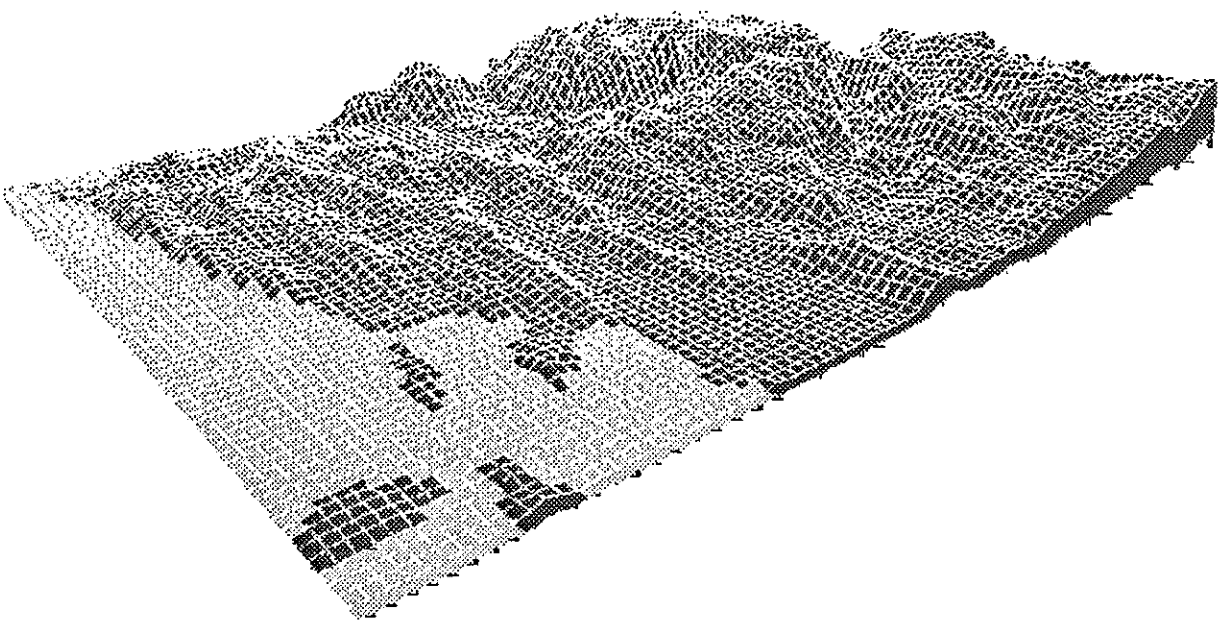
The Use of GIS and SGEOS data for Landscape Ecological Classification and Survey of Changes in Lan Use, Marginal Land, Set Aside Areas and Biotope Patterns of Agricultural Landscapes

Final report on contract no. 4109-90-10 ED ISP DK

Brandt, Jesper; Münier, Bernd ; Andersen, Erling; Christiansen, Ole ; Nielsen, Peter

THE USE OF GIS AND SGEOS DATA FOR LANDSCAPE ECOLOGICAL CLASSIFICATION AND SURVEY OF CHANGES IN LAND USE, MARGINAL LAND, SET ASIDE AREAS AND BIOTOPE PATTERNS OF AGRICULTURAL LANDSCAPES



Final report on contract no. 4109-90-10 ED ISP DK

Jesper Brandt, Bernd Münier

Erling Andersen, Ole Christiansen and Peter Nielsen

Content

1 Introduction . . . 3
1.1 Project overview . . . 3
1.2 Background . . . 3
- prior research . . . 3
1.3 Selection of test area Funen . . . 5

2 Setting up the basic GIS . . . 9
2.1 Introduction to GIS and geographical databases . . . 9
2.1.1 Basic characteristics of geographical data . . . 10
2.1.2 Theoretical framework of spatial data models . . . 11
2.1.3 A concept for an integrated hybrid GIS . . . 14
2.2 Implementation of an integrated hybrid GIS . . . 18
2.2.1 Choice of hardware & software components . . . 18
2.2.2 Data model of the implemented GIS . . . 19
2.2.3 Data conversion and exchange . . . 21

3 Setting up the database . . . 23
3.1 Definition of basic parameters . . . 23
3.2 Data and maps to be included . . . 23
- selection of relevant landscape variables . . . 23
- Northern part of Funen . . . 25
- Tågerup, municipality of Gundsø . . . 26
3.3 Data input, preprocessing and updating . . . 26
3.4 Examples of data analysis . . . 27

4 Evaluation of SGEOS data and scanned airphotos in relation to marginal land mapping and monitoring . . . 33
4.1 The GIS- and remote sensing-entrance ("top-down") . . . 33
4.1.1 AREA: A programme for semiautomatic delineation of small biotopes . . . 33
4.1.2 Specification of the programme . . . 33
4.1.3 Comparison to similar programmes . . . 34
4.1.4 The field test . . . 34
- Datasources . . . 36
- Results . . . 36
4.1.6 Monitoring of biotopes with AREA . . . 39
4.1.7 Conclusion . . . 41
4.1.8 Future research . . . 42
4.2.The small-biotope field-work-entrance ("bottom-up") . . . 43
4.2.1. Small biotopes and their growing importance in modern society . . . 43
4.2.2 Classification of small biotopes and changing scopes of the investigations . . . 44
4.2.3 The use of air photos in the small biotope investigations . . . 47
4.2.4 A framework for integration of SGEOS-data and scanned airphotos in a future monitoring system . . . 48

5 Summary and conclusion 53

References 55

Appendix 59
Appendix A. Public access to GIS and database implemented under this project 59
Appendix B. Overview on data handling capabilities of RUGIS 59
Appendix C. Structure of the programme AREA 60
Appendix D. GRASS 4.0 programs abstract 60

Acknowledgment and Copyright:
We want to thank those, who helped us and provided data necessary for this project. Copyright on black and white airphotos and digital elevation model is hold by Geodetic Survey (GI - KMS), Denmark. Copyright on digitized soil data, drainage pattern and histosol areas has Land Data Bureau, Vejle, Denmark. Colour airphotos from test area I - Funen - have been taken by Poul Christensen/GeoMasters and were scanned by Image House/Copenhagen. The colour airphotos from test area II have been taken by GEOPLAN, and were scanned at the Danish National Map & Cadastre, Copenhagen.

Printed maps have been used with permission from Danish National Map & Cadastre, Copenhagen.

1 Introduction

1.1 Project overview

This report is the final report on a research contract between the EEC Joint Research Centre (JRC) at Ispra/Italy and the Institute of Geography and Computer Science at Roskilde University Centre. This work is carried out as part of a joint research programme from JRC, the 'Less favoured areas programme' (LFA).

According to the contract, the study will consist of the following parts, piked from the proposal and agreed by the participants at a working group meeting in Trier in 1990:

I. Creation of a Geographical Information System (GIS) to a fully operational stage, including:
- Land use data
- Landscape ecological parameters relevant for description of the various land units in the test area
- test data set of SGEOS data (Second Generation Earth Observation Satellites) - with possibilities of continuously updating by new data sets.

II.a. Development and elaboration of methods for including analysis of scanned airphotos in the GIS.

b. Study of the possibilities to determine and map various small scale landscape elements - small biotopes - by means of the developed GIS.

III. Evaluation of the potential for using SGEOS data and/or scanned airphotos for set aside land management - both included planning and monitoring.

The first chapter of this report will bring an introduction to the background behind this project and a short introduction to the test area selected. Chapter two and three deal with design and creation of a fully operational GIS, including database setup and test data sets. In the forth chapter will be discussed the incorporation and analysis of scanned airphotos, plus possibilities for mapping of small biotopes. Last not least the report is rounded up with an evaluation of the research work done under the project.

1.2 Background

- prior research:

The Danish Marginal Area Research Project, published by the National Forest and Nature Agency under the Danish Ministry of Environment, has been carried out in the first half of the 1980'ies. A very important result of these investigations was a growing understanding of the fact, that marginalization tendencies can not only be seen as a problem in areas of generally less favoured natural conditions for agricultural production. In fact also the structure and dynamics of the more efficient and intensively used agricultural areas affects potentials for agricultural production within a given area. Everywhere local varieties in the natural conditions together with socioeconomic conditions can have important influences on the marginalization process.

In the Danish marginal soil investigations, the marginalization problems of the intensively used Weichsel Morainic landscape - comprising 2/3 of the total area of

Denmark - where found to be concentrated on four types of landscape elements (Agger and Brandt 1987, Agger et.al. 1987):

- dry, sandy soils in parts of the morainic landscape.
- histosol areas, located in former wetlands, pits and reclaimed areas.
- undulating areas with steep slopes, such as tunnel valleys and dead ice landscapes.
- small biotopes, lines and patches of uncultivated areas within the highly productive agricultural areas.

An earlier report - produced under the Less Favoured Areas Collaborative Programme - dealt with the development of methods of integrating SGEOS data with existing maps and filed collected data in a GIS. By means of this GIS, it should be possible to improve and actualise mapping of land use, land capability and relations to biotopes (Münier & Brandt 1990: The use of GIS and SGEOS data in landscape ecological analysis of marginal lands and small biotopes; final report on contract no.3734-89-06 ED ISP DK).

This first report primarily dealt with collection and preparation of input data necessary for further analysis. Furthermore some trials have been carried out for setting up a model on soil moisture, vegetation cover and soil organic matter, based on field survey and Landsat TM data. Another topic has been the integration of Landsat TM data and scanned airphotos for mapping purposes, in relation to their spectral and geometric properties. Last not least, a study on mapping of small biotopes based on textural analysis of scanned black and white airphotos has been carried out.

- ongoing research:

The present report must be seen as a continuation of our first project under the less favoured areas project, and research on utilization of GIS within the topics of mapping and landscape analysis of marginal soils and small biotopes.

In this project emphasis has been laid on the development of an integrated hybrid GIS, that could handle a variety of parameters and information-sources relevant for analysis and monitoring of the marginalization processes going on in the intensively used Weichsel Moraine landscapes of Western Denmark.

Because the so-called small biotopes has been seen as one of the main types of marginal land in this area, their incorporation into the GIS by extending the system with data from scanned airphotos has been an important part of the project. This way of incorporation has had a clear "top-down"-approach: Will it be possible to extended application of SGEOS-data and scanned airphotos to mapping and monitoring of all sorts of marginal land, including small biotopes? This approach will be evaluated in part 4.1.

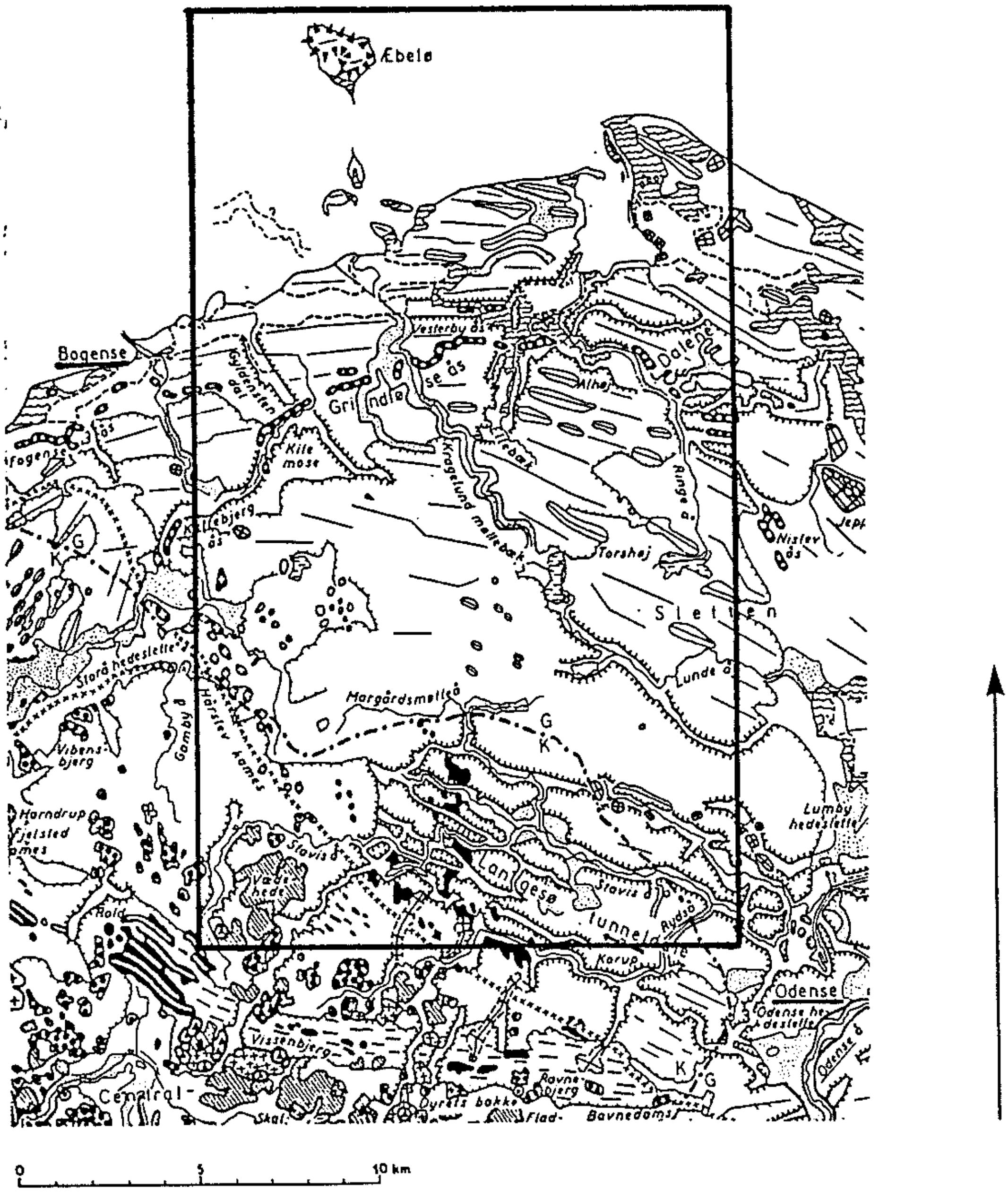
However, parallel to this project we have been working on another project, that has given an opportunity for an evaluation of the problem from another point of view by using the experiences from the Danish Small Biotope Project as a basically field-work-related mapping and monitoring system, to give an evaluation from a "bottom up"-approach: Can the mapping and monitoring of small biotopes be carried out more reliable and efficient through an incorporation of SGEOS-data and scanned airphotos into the used system? This approach will be evaluated in Part 4.2.

1.3 Selection of test area Funen

In connection to the first project under the collaborative programme, a test area of 15*25 km has been selected from the northern part of the Danish island Fyn. This area covers different types, typical for the Danish Weichsel moraine landscape.

The main part of the test area consists of a weakly undulating bottom moraine with clay sandy to sandy clay soil. The northern part is very flat, drumline characterised, with two rows of eskers and some extramarginal stream valleys. Here also three reclaimed areas can be found, which have light grey sandy soil of marine deposits, followed by freshwater deposits and organic soils in some extramarginal stream valleys more inland.

The southern part, reaching into the middle of the island, is dominated by hummocky or pitted landscape due to dead ice formations in the west, and three parallel running tunnel valleys in the east. One of the typical flat topped ice lake hills with heavy clay soil can be found in the south western corner of the area.



Source: Bulletin of the Geological Society of Denmark. Vol. 15, Part 1, 1962

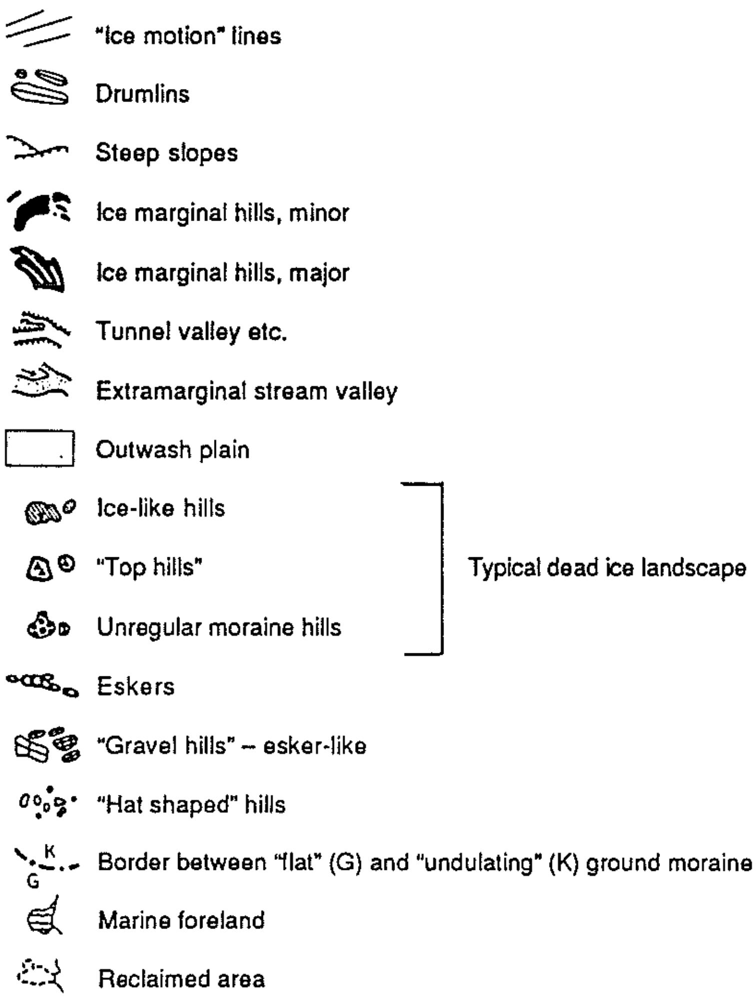


Figure 1: Part of map on landscape forms in the Danish island Funen, covering the test area I - Funen (outlined) and its surroundings. The map shows the main glacial landscape features, as mentioned in the text on this page. Scale 1:200.000

Test area I is defined by the following borders:

Projection **UTM** system, zone **32**, in **METER**.

- **whole area:**

north: 6168000

west: 570000 east: 585000

south: 6141990

grid-cells in raster (meter):
x = 30 ===> 500 cells (pixels) ===> 15000 meter
y = 30 ===> 867 cells (pixels) ===> 26010 meter

- **subarea, as used in plate 1 and 2:**

north: 6163800

west: 574000 east: 581200

south: 6154800

grid-cells in raster (meter):
x = 30 ===> 240 cells (pixels) ===> 7200 meter
y = 30 ===> 300 cells (pixels) ===> 9000 meter

2 Setting up the basic GIS

2.1 Introduction to GIS and geographical databases

A common definition of a GIS is given below, while other definitions can be found in literature (Guptill 1988, GIS SOURCEBOOK 1990, NCGIA 1990).

> **A Geographic Information System is a powerful set of tools for collecting, storing, transforming, retrieving and presenting of geographically related data and information by user interaction.**
> (Burroughs 1986, modified).

Setting up system demands to a GIS usually requires existence of a well defined purpose. Otherwise it may be very hard to define demands for a general purpose system which may be used in many different applications in future research work. When defining demands for the system to be established at Roskilde University in connection to the marginal soils project, requirements were derived from experiences and theoretical considerations upon landscape analysis and landscape ecological mapping.

In general, applications within land resources analysis and landscape ecological mapping are characterized by a combination of deductive and inductive methods, requiring a combination of different types of input data to be stored, handled and output from the manipulation and analysis steps.

Most real world phenomena show an infinite complexity, hence the resulting amount of data necessary for a true representation of one of its features cannot be stored in a database of some limited extension. As a consequence, in an imaging or mapping step some reduction of this infinite amount of raw data has to be done. Data compression can be obtained by reducing the spatial resolution while rasterising an image, or by divide a landscape into homogeneous units with well defined borders, using a classification process to produce a thematic map. This incorporates the disadvantage that information in a thematic map is bound to a certain purpose, making these extracted information not always applicable to other purposes.

Transitions between landscape elements are often weak and badly defined in the landscape, while they have to be represented by sharp borders in thematic maps. Overlaying such thematic maps in an analysis process may cause problems with sliver polygons and mapping inaccuracy, making it important to store and preserve as much information from the raw data as possible in a GIS. A potential advantage of GIS should be, that mapping and analysis can be done from terrain variables, stored as continuous data (satellite images, DEM, etc.), rather than having to reduce information to classified maps with discrete data before entering them into the system. Such flexibility is important, because no single land classification is considered optimal for all applications.

As a consequence of this contradiction between necessary compression and full access to raw or partly processed data, the system should support handling and analysis of these different kinds of data. Furthermore it should be possible to read printed and digital topographic and thematic maps into the system, because lots of information only is available from existing maps. In the map creation step, information should be presented as raster images of continuous variables and/or as thematic maps in raster or vector format, and a combination of both.

The main components of a GIS are shown in figure 2, and will be discussed in the following. They are related to the functions mentioned in the above definition of a GIS, and consist of:

- Data input and verification
- Data storage and database management
- Data output and presentation
- Data transformation
- Interaction with the user

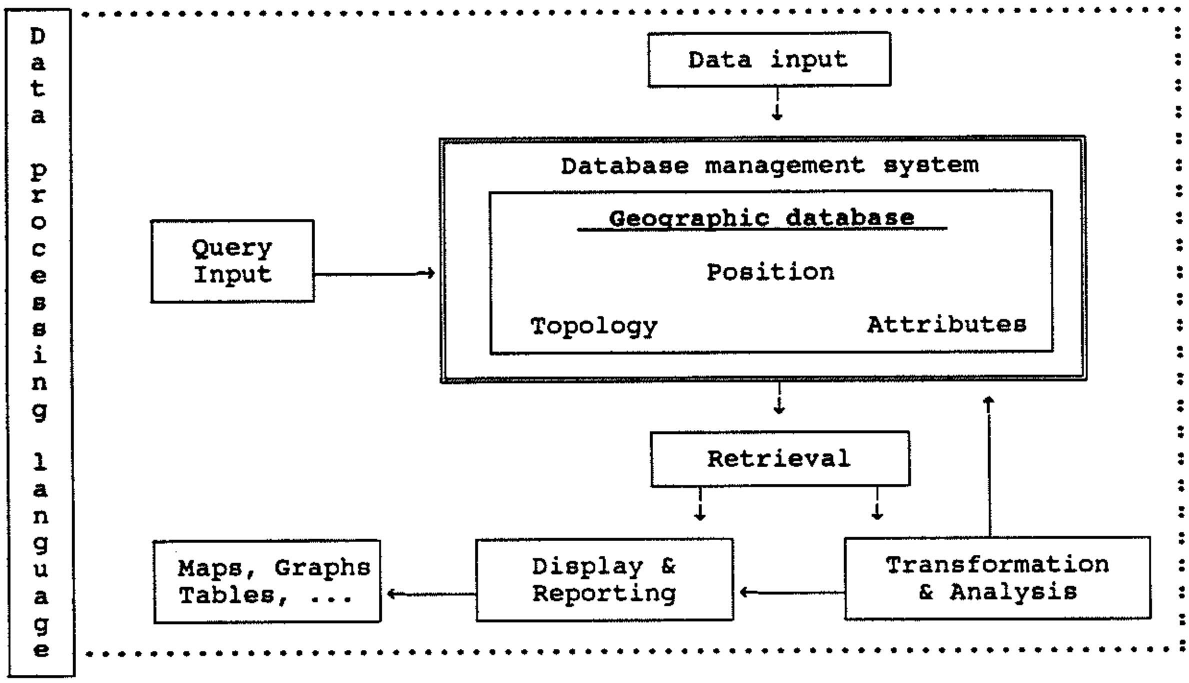


Figure 2: Sketch of main components of a GIS, with the geographic database as its central part. (Burroughs 1986, modified)

2.1.1 Basic characteristics of geographical data

Spatial data or information consists of entities, i.e. things that exists and are distinguishable, where we can tell one unit from another. These entities are defined by two basic characteristics, attributes (variables class, value, name, etc...) and a position in space. Dealing with geographic data in many cases adds time as a third characteristic. This means that a geographic entity in a constant location may change its attributes, or it changes location while retaining the same attributes, or both are changing.

Processing geographic information embraces handling of all three basic characteristics - space (locational data in up to three dimensions x,y,z), attributes (nonlocational data) and time (a possible forth dimension) -, as they are illustrated in Figure 3 below. Effective geographic data management requires locational and nonlocational data be variable independent of each other, with respect to changes over time.

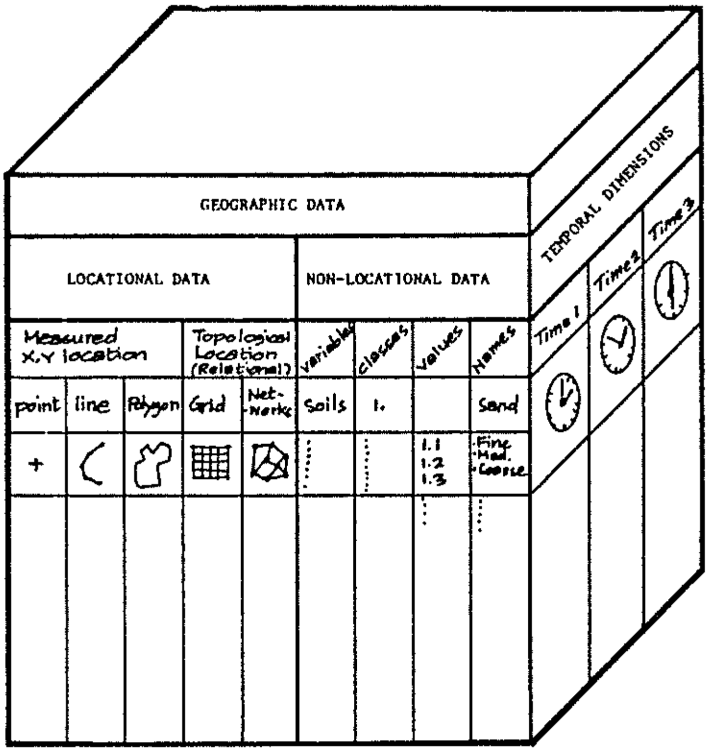


Figure 3: Three conceptual components of a geographic based information system. (Dangermond 1990).

In many applications some dimensions can be kept constant, as is the case for mapping of the earths surface were only two dimension (x,y) are need and the third is kept constant. Elevation as in digital elevation models is not a 'real' third dimension, but has character of an attribute to the two other, in literature usually called 2½ dimensional, which can be quite misleading. In the same way, a time series along with a profile on earth surface only has two dimensions, varying along the profile and in time.

2.1.2 Theoretical framework of spatial data models

A conceptual framework and comparison of spatial data models is given by Peuquet (1990). As the word 'model' implies, the most basic characteristic of a data model is that it is an abstraction of the real world, with respect to a given purpose or set of purposes. Each data model therefor is a human conceptuation, representing reality with a varying level of completeness and tailored to a given application.

With respect to data representation only, a data model may be defined as a general description of specific sets of entities and the relationships between these sets of entities. Another way of defining a data model was given, where a data model consists of three components; a collection of object types, a collection of operators and a collection of general integrity rules. This second type of data model provides both a formal means of representing data and a means of manipulating within such a representation.

Designing data models means, that data have to be seen at different levels of abstraction, progressing from reality, over abstract but user oriented data structure, to the concrete machine oriented storage structure. No universal agreement has been made about how to limit these steps, but for the purpose of this report a general division into four levels will be adopted from Peuquet (1990), as can be seen below in figure 4:

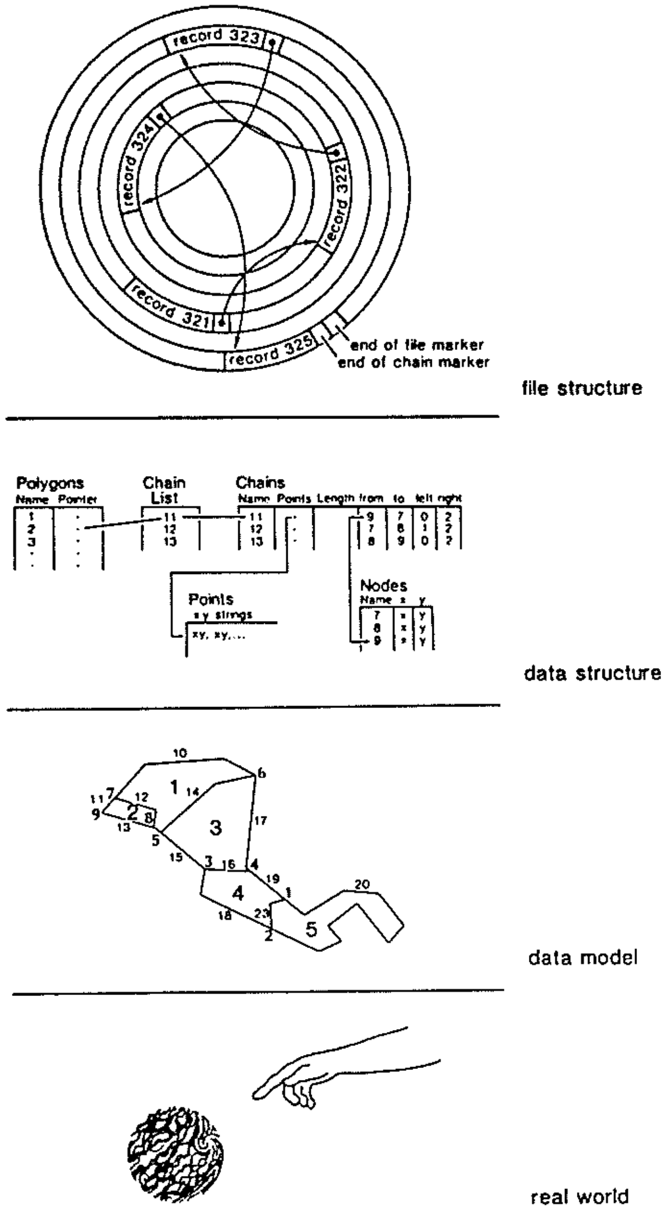


Figure 4: Levels of data abstraction, from real world phenomena to data file structure on computer disks (Peuquet 1990).

Reality	- the phenomenon as it actually exists, including all aspects which may or may not be perceived by individuals.
Data model	- an abstraction of the real world which incorporates only those properties thought to be relevant to the application or applications at hand, usually a human conceptuation of reality.
Data structure	- a representation of the data model often expressed in terms of diagrams, lists and arrays designed to reflect the recording of the data in computer code.
File structure	- the representation of the data in storage hardware.

As can be seen from this, the term **'data model'** in this context has evolved to be **a human conceptualization of reality, without consideration of hardware and other implementation conventions or restrictions.** As a consequence, even skilled GIS users only have to understand, how a data model reflects reality and which types of data storage and manipulation this would allow. It is not necessary to care about implementation of the data model on a computer. Furthermore, any data model implemented on different types of computers can be used the same way on all implementations. A GIS-package ported from one type of computer to another without changes affecting the GIS's implicit data model, will provide the same data processing facilities and give identical results.

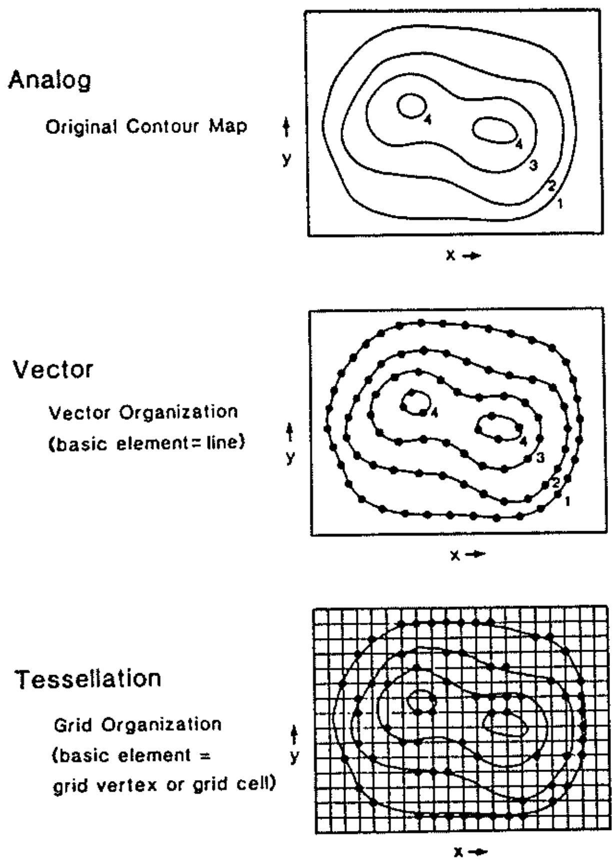
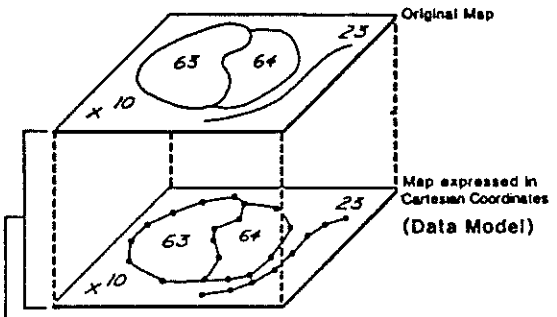


Figure 5: Basic types of spatial data models, vector and raster representation of an analog reality (Peuquet 1990)

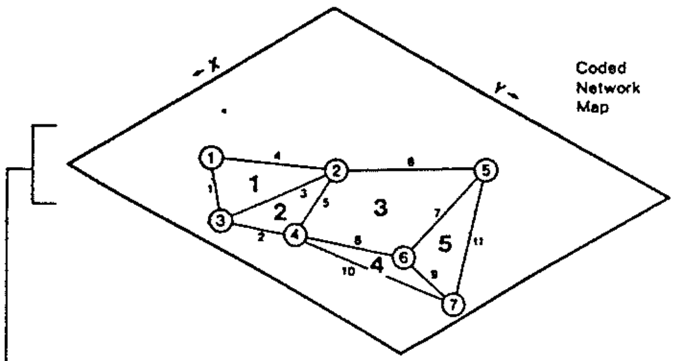
Usually there are two basic types of spatial data models, vector or raster representation - see figure 5. Examples of traditional spatial vector representations are the 'spaghetti' data model, where each entity solely is referred by its location in space, without respect to the other entities such as nodes, connecting lines or neighbourhood (figure 6a). These kind of relationships is taken care of within the topologic data model, where topology is defined explicit in the model and the resulting vector representation inside a database (figure 6b).

For spatial raster representation, usually a simple grid is used, defining both attributes and implicitly referring topology too. Sometimes a compression of these rectangular grids is used in run-length encoding or quadtree structure. Other kinds of raster models to be mentioned are non-rectangle based forms as regular triangular or hexagonal networks, only used in special applications.



Data Structure

Feature	Number	Location
Point	10	X,Y (Single Point)
Line	23	$X_1Y_1, X_2Y_2, \ldots\ldots X_nY_n$ (String)
Polygon	63	$X_1Y_1, X_2Y_2, \ldots\ldots X_1Y_1$ (Closed Loop)
	64	$X_1Y_1, X_2Y_2, \ldots\ldots X_1Y_1$ (Data Structure)



Link #	Right Polygon	Left Polygon	Node 1	Node 2
1	1	0	3	1
2	2	0	4	3
3	2	1	3	2
4	1	0	1	2
5	3	2	4	2
6	3	0	2	5
7	5	3	5	6
8	4	3	6	4
9	5	4	7	6
10	4	0	7	4
11	0	5	5	7

Topologically Coded Network & Polygon File

Node #	X Coordinate	Y Coordinate
1	23	8
2	17	17
3	29	15
4	26	21
5	8	26
6	22	30
7	24	38

X,Y Coordinate Node File

Figure 6: Two common types of vector data models (Peuquet 1990):
a - the 'spaghetti' data model
b - the topologic data model

2.1.3 A concept for an integrated hybrid GIS

The following two demands to the system have been compiled from the needs of the current project, as mention in the items above:

A. The system should provide a tool to be used in ongoing research on mapping of land resources and marginalization tendencies in the open land. Within this work emphasis has been laid on developing methods of how to integrate SGEOS images (Second Generation Earth Observation Satellites) with scanned airphotos, existing maps and field sampled data in a hybrid GIS. This GIS should be capable of improving and actualizing mapping of land use, land capability and relations to nature conservation and recreational areas.

B. Furthermore it was aimed to set up and implement an **operational working system**, for consideration of practical experiences on a test area. The system should be based on existing components. Incorporating existing software packages instead of self development means, that emphasis could be put on design of the whole system's concept and on integration of its components.

The following types of data should be handled in the GIS:

- continuous data (images and feature maps - raster format), that
    - have a highly variable areal resolution, but weak and blurred borders between different land units,
    - can give a true image of many features in the landscape,
    - can be combined with each other with little loss of information compared to classified maps.
- discrete data (classified images or thematic maps - vector or raster format), that are
    - homogeneous areas, delimited by sharp borders, and
    - segmentation of the landscape.

To obtain these features, the system to establish should consist of:

- a **hybrid GIS** capable of **handling and combining raster and vector** data.
- an **integrated image processing system and GIS.**

These demands emphasize, that free transfer of data within the entire GIS must be an essential part of the concept, making it possible to satisfy requirements to flexibility in integrated analysis and mapping. Different ways of system integration will be elaborated in the following sections.

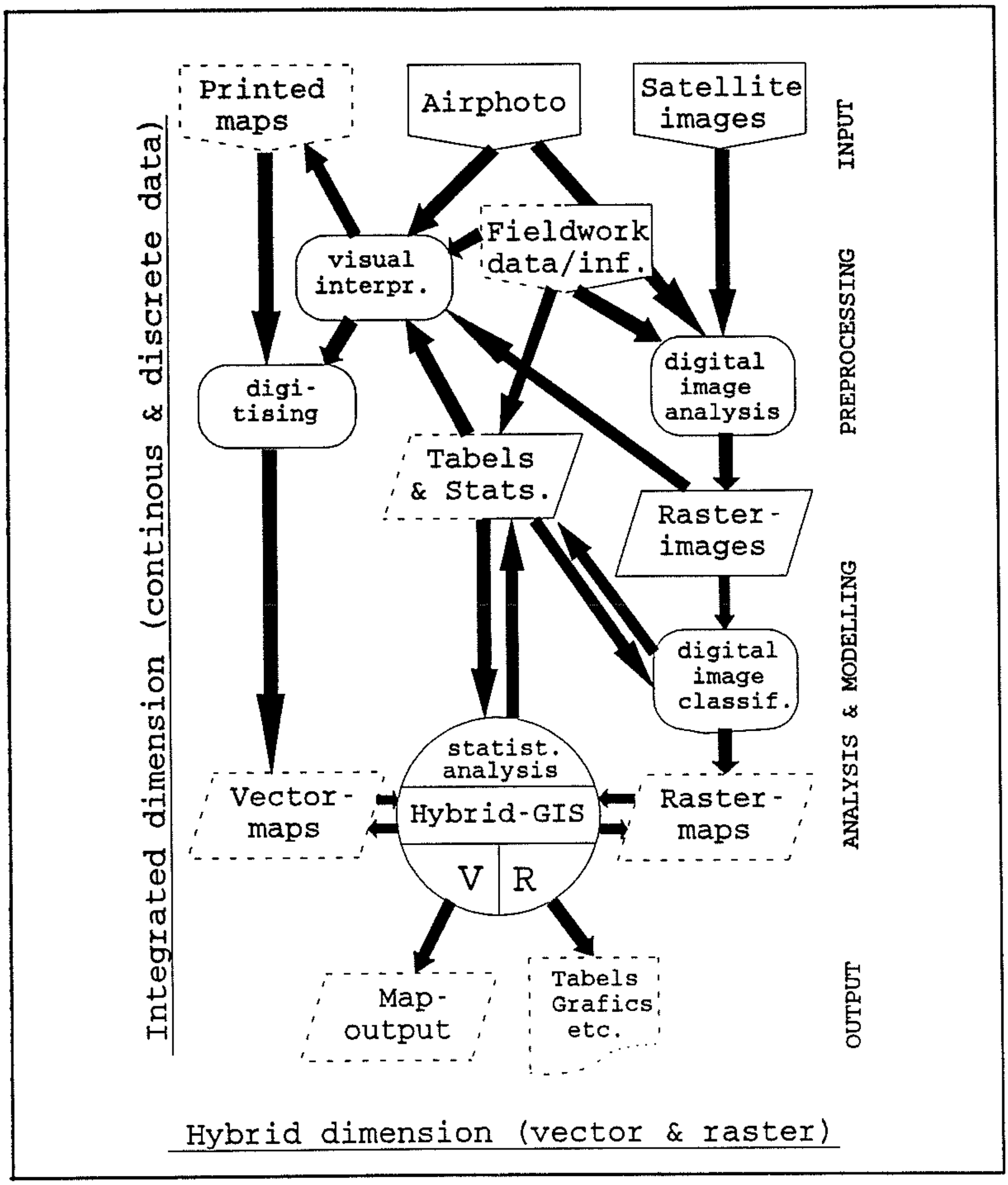


Figure 7: A diagram showing integrated and hybrid dimensions within a GIS, to be used within landscape analysis and thematic mapping. In the figure, emphasis has been put on displaying principles of data flow and data processing inside the system. In vertical direction it shows the integrated dimension, combining handling of continuous and discrete data. These involves steps from raw data sampling and acquisition, preprocessing, interpretation and classification. The horizontal dimension shows analysis and modelling of vector and raster data in a hybrid system, map and data output and report generation. Boxes concerning continuous data are outlined with straight lines, while discrete data have dashed borders.

- Fundamental considerations on system integration:

An optimal solution would be one hybrid system, designed as an integrated digital image analysis system and GIS with combined vector and raster handling. Such a kind of system is not jet available on the market in an operational working form, that meets the demands mentioned above. This again leads to the necessity of considering and discussing modes of integration to have in mind during system selection and implementation.

- internal storage integration:

First of all it is advisable to have a storage locations of images, maps and other data, where they are accessible from the entire system. This can be done by hardware integration, using only one hardware platform for all applications. Alternatively a software integration can be used, if different types of computer hardware have to be included into the system. They can be linked together via a data network running a file server protocol, making it possible to have one logical disc structure even if the files are physically distributed over several harddisks, placed on different types of computers.

Using a distributed file structure makes it is important to define, if only text files should be read across the system, or if this should include binary data files too. As internal data storage format of characters and numbers can differ between different types of computers, a common internal data storage formats must exist to make it work correctly. The first case usually gives no problems, as many computers store characters in ASCII format as a text file standard. In the second case, a common binary data standard as defined by IEEE must exist, otherwise problems may occur when exchanging integer or real numbers.

- application programs integration:

Discussing the integration of applications, three basic **levels of integration** can be defined in an increasing order:

1 - **external**: Data transmission by converting between data exchange formats. Most packages provide a possibility for data exchange with external applications, using a special format with reduced content of information and only little structure. In many cases these data exchange formats are simple text files which are easy to transmit to foreign sites via a data network. This requires usually a 3 steps process (= export/conversion/import), but many packages support a number of commonly used exchange formats making the conversion step unnecessary. Advantages (+) and disadvantages (-) of integrating packages at this low level are:

+ necessary import/export facilities often exist inside packages.

+ conversion programs are easy to write.

+ in some cases data can be exchanged between packages which have common text (but not common binary) representation of numbers.

- slow and not user friendly, ancillary information stored in a header etc. is often lost and has to be regenerated by the user.

- data stored in exchange format occupy huge amounts of disk space.

2 - **internal**: Data transmission by converting directly between internal data formats of different packages. Information is read from files/database and as much information as possible is preserved by transferring it to the output data set. This

requires usually a 1 step process (= conversion), and is a reasonable way of linking foreign packages together.
+ direct conversion between packages in one step.
+ more user friendly, no or little additional information has to be provided by the user under conversion.
+ no intermediate data sets are created.
- conversion programs must be able to read/write all information from the data files, including header etc., which makes programming more complicated.
- if different computers use diverting binary data storage formats, special conversion routines must be implemented to read/write these data.

3 - build-in:

a - Application programs of different systems are able of recognising data formats automatically and read/write them directly or execute the necessary conversion without use interaction. This is a kind of virtual image storage, where 0 steps of user initiated conversion are required. It has been seen in special cases, e.g. with a PC working as a kind of display and local workstation, linked to a remote host computer.

b - Only one data format/database exists in the entire system, and no conversion at all is necessary. This can be done on systems which designed as fully integrated image analysis systems and GIS.

Generally it can be stated that level 1 represents the absolute minimum, which is supported as a standard by many packages, but which is not satisfying due to lack of user friendliness. Level 2 would be the usual way of doing it for a system based on components available on the market. Level 3 is supposed to be state of the art, and requires an integrated system to be designed as such.

2.2 Implementation of an integrated hybrid GIS

2.2.1 Choice of hardware & software components

Based on definition of system demands, the next step when setting up the system at Roskilde University was selection of hardware and software components which would meet most of the criteria defined in the preceding sections. It turned out, that no single available system could satisfy all demands, making it necessary to compose a modular system. For each component a application package available on the market has been chosen, selected to fit the demands and to supplement each other. The main software components are today:

- digital image analysis package (ERDAS - raster image and GIS)
- hybrid GIS (GRASS - raster and vector map analysis plus digital terrain modelling)
- statistical package (SAS)

Concerning the hardware, most of the system has been based on a UNIX workstation environment, which has been established at the Institute of Geography and Computer Science since 1989.

* ERDAS and GRASS are running on two SUN SPARC 1+ and SUN SPARC IPC workstations under UNIX.
* ERDAS is running on a PC 386 under DOS.
* SAS runs on a PC network under DOS.

In figure 8 is given a sketch of RUGIS, showing the hardware equipment together with the main software components. All computers are connected via the universities local area network (RUCLAN), using SUN's NFS (network files system) for transmission and sharing of harddiscs by several workstations at a high speed, making data stored on one disc available to all of them. Furthermore RUCLAN is connected to DENET, the danish research institutions network. Via DENET connection to other international networks can easily be establish.

It is not the scope of this report to describe and analyze all packages separately, and therefore only a short description of RUGIS's data handling capabilities can be found as a summary in appendix B.

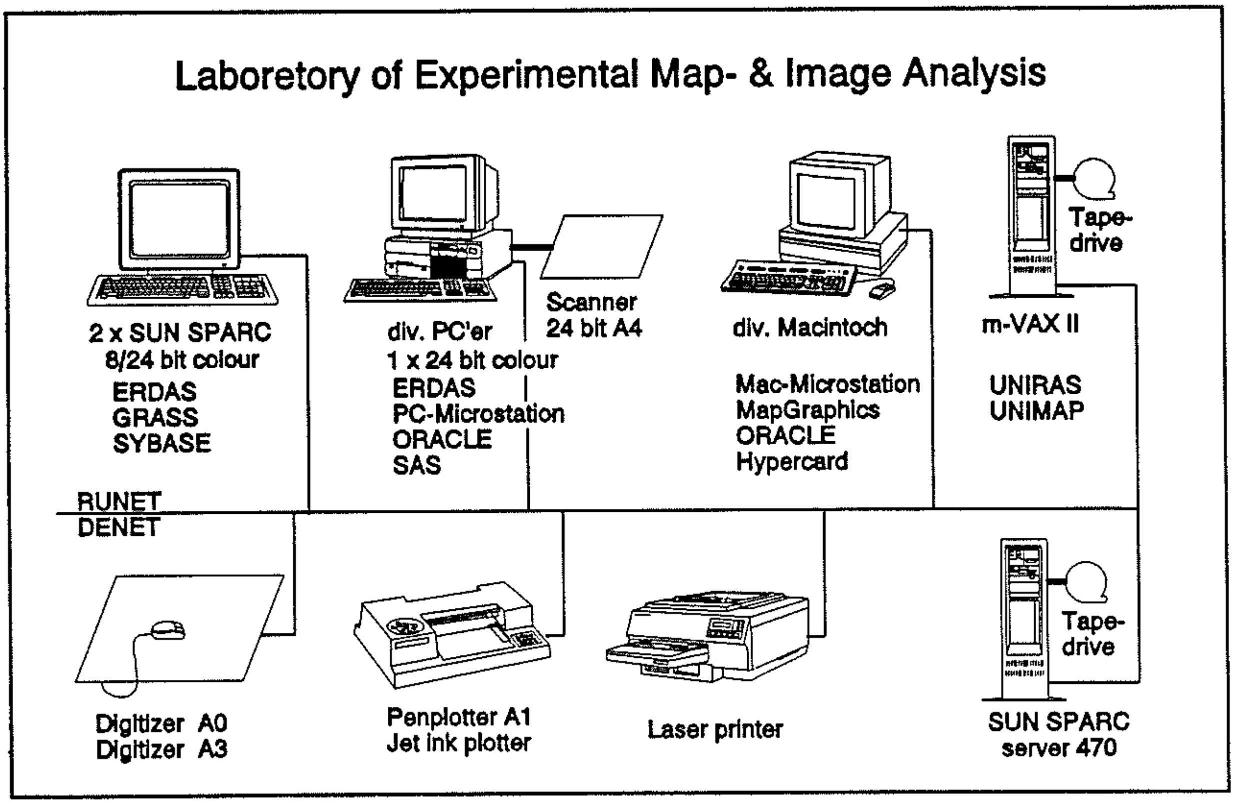


Figure 8: Overview of main hardware and software components within RUGIS, utilized within this research project.

2.2.2 Data model of the implemented GIS

The main database of RUGIS has been set up under GRASS and ERDAS, with the possibility of data exchange and conversion between these two systems. The data model of GRASS and ERDAS will be discussed with respect to what has been discussed in section 2.1.2.

• ERDAS:

ERDAS is mainly a raster data processing system with emphasis on digital image analysis and resource mapping based on geographical data. A minor but still growing part of ERDAS handles thematic maps in raster format. All raster data are stored in a very simple database, i.e. as a stack of geo-referenced maps. Display and analysis of multiple images/maps can be done only, if their boundaries and spatial resolution matches. Several band of an image usually have to be stored in one file for processing, while thematic maps contain one layer per file.

This is a very straight way of building a database, seen from the system developers and programmers point of view, as no dedicated database management system is needed to handle these separate files. A user on the other hand may find this confusing and time consuming, as a lot of copying, subsetting, stitching and mosaicing has to be done, if he wants to incorporate the same images/maps in different combinations.

For some years ago, ERDAS made an agreement with ESRI company concerning their system ARC/INFO, with the intention of bringing the two systems closer together and make them supplement each other. If you purchase both packages together with the so called 'life-link', it will be possible to integrate data from ERDAS and ARC/INFO in screen display, analysis and plotting.

This agreement may be the reason why ERDAS's vector handling is build up around a quite simple 'spaghetti' data model, storing every vector as a distinct entity, i.e. every point, line, polygon at a time. No topology exists, and all border lines have to be defined separately for each polygon. A border between two adjacent polygons is stored as two separate lines, one for each polygene. The two lines not necessarily coincide and slivers between them may occur.

Furthermore, only one attribute can be attached to a vector entity, no attribute tables are possible. ERDAS uses vector data for screen display and plotting, separately overlain on a raster image. Furthermore it is possible to cut out parts of a raster image or to define training areas for statistics computation in connection to image classification.

• GRASS:

GRASS has originally been developed as a raster GIS for earth resources analysis, but has with the new release 4.0 from summer 1991 been expanded to fully topological handling of vector data.

Geographical boundaries and subareas:

Using GRASS the user has to set up LOCATIONs and MAPSETs as database locations for storing different geographical areas. Typically a LOCATION will cover the overall working area, under which different MAPSETs can be defined. All data within a chosen LOCATION can be accessed and read, but storage of new data is allowed only by writing into the MAPSET actually in use. Regardless of the default region definition within a LOCATION, single maps may refer to subareas or extend over the borders defined.

Most operations can be executed on maps with diverging borders. Furthermore it is possible to work on subareas, geographically limited by a window (rectangular, regular area) or a mask (unregular area), defined by a raster or vector map. But be aware, if a subarea has been defined once, you have to reset this definition to work on the full area again. Usually the system will not ask wether or not you still want this limitation for the next operation.

Raster data:

Raster data are stored as matrices in uncompressed or compressed form. Every thematic map layer or image band is stored separately with its attributes, boundary definition, statistics and history attached.

To handle multispectral images as a whole, so called 'imagery group files' can be created. Imagery group files are tables referring to a set of single band images or maps, to be used in multispectral analysis. Images can be grouped independently of each other and in unlimited combinations, providing very flexible access to image data, with almost no extra disk capacity required.

Many raster map operations as reclassification, rescale etc. do not actually recompute the whole raster data set. Instead output consists of a table, referring values in the output map to corresponding value(s) from the input map, thus saving processing time and disk space.

Vector data:

Fully topological handling and storage of vector data has been implemented into GRASS since version 4.0 last summer. It still lacks functions for some basic operations on vector data. Important features are combination of vector map layers by overlay/intersect, were lines and topology can be handled, but attribute assignment to the new map is still missing. Other examples are area computation on polygon maps, and screen display and plotting of polygons using filled colours, hatching or other patterns.

These functions are under development and will be included within the next major release. In fact some of them already exist in GRASS source code as 'alpha' versions or third party 'contributions', from where they have been compiled into GRASS at RUC and work quite well. The only point is that there is no secure for reliability of the results.

GRASS can be linked to a RIM for multiple attribute handling, which is a relational database in public domain. Until now, this has not been set up and tested in our installation of GRASS at Roskilde.

2.2.3 Data conversion and exchange of external data

internal conversion:

Conversion from vector to raster and vice versa can be done by GRASS, including attribute support providing an link between raster and vector parts of the system. ERDAS converts vector to raster one way.

Regarding linkage between digital image analysis under ERDAS with GRASS, raster data can be imported from ERDAS to GRASS including geographic references, class names and colour assignments via a GRASS-routine. A similar conversion the other way round has not been implemented jet, so GRASS raster data have to be loaded into ERDAS as a foreign data set, loosing all information about geographic references, class names and colours.

Vector data exchange between the two systems goes via one of two well known and commonly used exchange formats. The best functionality is provided by DLG (Digital Line Graph), an ASCII text format including arcs, topology and attributes. Another possibility would be ARC/INFO's external exchange format (from ARC/INFO generate/-

ungenerate), which is a simple list of arcs without topology inside, optionally supplemented by lists of attribute label points and class names. Both formats will automatically be reorganised at the receiver to fulfil all the requirements mentioned above.

exchange of external data:

For exchange with other databases and sites the same formats as mentioned above should be preferred, but others are available inside GRASS too. Regarding data input from the Danish ADK, a dedicated program has been written to convert database output of those vector maps to ARC/INFO G/U format for input into RUGIS.

3 Setting up the database

The GIS chosen for this project and its implemented data model define database structure and concept. The following sections will define basic parameters for inputting maps and data into the system.

3.1 Definition of basic parameters

- common coordinate reference: All maps/images have been geometrically corrected and rectified to meet standard UTM zone 32 coordinate system and projection. The standard Danish ellipsoid used is 'Hayford-1924', corresponding to the 'International 1909' as one of US Geological Surveys ellipsoids included in many standard GIS and image analysis packages.

- spatial resolution for raster maps and geometrically corrected images has been set to 30x30 meters, corresponding to Landsat TM data's nominal ground resolution. Exceptions are colour airphotos from test area Funen, which have been set to 5x5 meters, and colour airphotos used in connection with mapping of small biotopes in test area Gundsoe with 1.25x1.25 meters.

- location and delineation of test areas has been presented in chapter 1.3.

3.2 Data and maps to be included

- selection of relevant landscape variables

The database established under this project contains maps and data for test area I, respectively test area II. Selection of relevant maps and data has mainly been based on the four types of landscape elements pointed out by the Danish marginal soils investigations.

These elements have been mentioned earlier in this report, and will be discussed briefly in this section together with related landscape variables, which can be seen as the main indicators for pointing out less favoured areas and marginalisation tendencies within the Danish Weichsel Morainic landscape:

a - dry, sandy soils in parts of the morainic landscape.

Generally soils are the substratum for growing plants, seeds, forests etc. In almost all parts of Denmark the thickness of glacial deposits is at least a few meters, but commonly they will be several tens and up to some hundred meters. As a consequence, bad rock generally can not be found as a growth limiting factor within the plants root zone. The only type of none penetrable layer for plant roots in Denmark are iron-aluminium concretions, which can be found in about 1 meters depth on acid soils. These layers are connected to outwash plains in western Denmark and outside the current test areas. Furthermore, many of those have been broken up by deep-ploughing.

The major limiting factor for agricultural crop yield is plant available water (Madsen 1983 and 1986). Despite the fact that most areas will percept a water surplus from precipitation over the year due to humid climatic conditions, in sandy areas infiltration is very fast and the soils water storing capacity relatively low. In dry summer months this results in lack of plant available water in the root zone, which has to be added by irrigation.

Intensive irrigation of large areas can have negative consequences for the environment. A lowering of the local ground water table will drain wells, lakes, water courses and wetlands for their water supply. Raising concentration of pollutants in these recipients will threaten not only biological habitats, but even supply of drinking water to men and industry can be affected.

Factors to map will be infiltration and root zone capacity (RZC), bases on maps of **soil texture** and **organic matter**, added with **geology** in 1 meters depth.

b - histosol areas, located in former wetlands, pits and reclaimed areas.

Another limiting factor for plant root development can be **histosols** with very high ground water table, limiting root development in depth due to lacking air/oxygen content in water saturated parts of the soils profile. Potential agricultural production in these areas will normally be less than on well drained soils, making such areas obviously for reestablishment of fallow land under natural conditions, small biotopes etc.

c - undulating areas with steep slopes, such as tunnel valleys and dead ice landscapes.

Steeper slopes can be impossible to cultivate with modern machinery, allowing harvesters and tractors to operate only at slopes up to about 12%, while some crops as sugar beats only accept up to 6% slope. On the other hand, a minor slope will ensure better drainage conditions than a totally flat area. Exposition of fields to the sun usually may be neglected, as the steepest slopes are excluded from cultivation. Finally, some risk of soil erosion may exist too, but is usually not very severe and will be neglected too in this project. Slope steepness can be derived from a **digital elevation model (DEM)**.

d - small biotopes, lines and patches of uncultivated areas within the highly productive agricultural areas.

Marginalization tendencies can not only be seen as a problem in areas with generally less favoured natural conditions for agricultural production. They also involve effects of the structure and dynamics of more efficient and intensively used agricultural areas, where there can be found marginal (set aside) land consisting of minor uncultivated areas. These small biotopes are together with larger biotopes of great importance for both agricultural, ecological and recreational reasons.

Conceptually these biotopes can be seen as a network that is embedded in matrix of cultivated fields, with the small biotopes having great importance as connecting elements and spreading corridors. It will therefor be of great interest to map locational and historical development, for biotope types and patterns as well as the underlying matrix of actual and potential utilisation of the open land.

Mapping of small biotopes has been based upon **field work** and interpretation of printed topographical maps as well as airphotos. Tests have been carried out for identifying small biotopes from scanned airphotos, with semiautomatic delineation of patch biotopes. The underlying matrix of cultivated field - land use - can be mapped in **field** or from **Landsat TM imagery**.

- Northern part of Funen (I):

The database established under this project contains data on the following variables for the whole test area 1, except colour airphotos which only exist for a minor subarea.

data and maps, to be stored in the database	type V	type R	source	form
base maps:				
• soil samples, own and governmental	S		ADK	p/d
• soil classification (JB-maps)	P		ADK	d
• geology in 1 meters depth	P		DGU	p
• histosol areas	P		ADK	d
• drainage network	L		ADK	d
• digital elevation model		R	KMS	d
• administrative boundaries (municipalities)		R	ADK	d
remote sensing data:				
• Landsat TM image May 15th 1988		R	EOSAT	d
• Landsat TM image May 18th 1989		R	EOSAT	d
• scanned IR colour airphotos, May 15th 1988		R	photo	p
derived maps:				
• contour lines, interval 2.5 meters	L			
• slope and aspect maps		R		
• morphographic features		R		
• drainage basins and network	P&L	R		
• vegetation coverage i maj 1988 and maj 1989		R		
• derived soil texture from Landsat TM		R		
• derived soil organic matter from Landsat TM		R		

- type: map originally received in raster (R) or vector (V) format, conversion has been done later on. Types are subdivided according to entities: site (S), line (L) and polygon (P).
- source: Institution providing and holding these maps and data. An explanation will follow in the next section 3.3.
- form in which data and maps were received: printed (p) or digital (d)

- Tågerup, municipality of Gundsø (II):

For the second test area, a database with a minor set of data has been established.

data and maps to be stored in the database	type V	type R	source	form
• one scanned colour airphoto from may 1990.	R		photo	p
• mapping of small biotopes for a minor subarea	P&L		field	p
• soil samples, governmental	S		ADK	d
• soil classification (JB-maps)	P		ADK	d
• histosol areas	P		ADK	d
• drainage network	L		ADK	d
derived maps:				
• small biotopes	P&L			d

- type: map originally received in raster (R) or vector (V) format, conversion has been done later on. Types are subdivided according to entities: site (S), line (L) and polygon (P).
- source: Institution providing and holding these maps and data. An explanation will follow in the next section 3.3.
- form in which data and maps were received: printed (p) or digital (d)

3.3 Data input, preprocessing and updating

This section will give a very brief description of data and maps read into the database, their origin and content.

• digital maps

The digital maps included into the database for both test areas have been received on floppy disk or tape, geo-referenced with respect to the UTM coordinate system zone 32, which covers almost all parts of Denmark, except the most easterly parts of the island of Sealand and the island of Bornholm. Test area II locates just east of the transition zone from UTM-32 to UTM-33, but UTM-32 can still be used without any practical problems. Locational precision required is much less than distortion originating from this change of UTM zones, as all digital maps from the ADK (ArealDataKontoret = Bureau of Land Data) are manually digitized from 1:25.000 topographical map sheets, only ensuring an overall accuracy around 15 meters.

The digital elevation model for test area I is a subarea from a prototype DEM, produced at the Danish Geodetic Survey (KMS) for orthophoto production purposes. It has been created from scratch by analyzing stereo pairs of black and white airphotos on a stereoplotter, storing terrain height every 50 meters. This resulted in a DEM with a ground resolution of 50x50 meters, referenced to UTM-32 coordinates. Data have been received on magnetic tape as columns with UTM and elevation, which have been compressed into a 50 meter grid. Subsequent the raster maps has been resampled to 30 meters, to match Landsat TM image resolution.

• printed maps

Part of a 1:25.000 map sheet showing geology in 1 meter beneath surface has been manually digitized in connection to this project. The printed map has been drawn by the Danish Geological Survey (DGU), based on topographical maps 1:25.000 from the Geodetic Survey. The same topographical maps have been used to produce ADK's maps and for geometric correction of satellite images and scanned airphotos from test area I.

• Landsat TM Images

Work with satellite images has been based on two Landsat TM scenes, path/row 195/21, acquired at May 15th 1988 and May 18th 1989. The weather conditions in cases was good, and the images received are of good quality, free of clouds and with only little atmospheric haze.

In order to insure that image pixels refer to the correct ground features, a geometric correction was performed. As basic map the topographical maps in 1:25.000 were used to pick up ground control point coordinates. Registration of the image covering the project region was performed as NN-resampling to 30 x 30 meter pixels, using a 1.degrees polynomial. The resulting RMS-errors of the polynomial-equalizations were about 1 pixel.

• IR colour airphotos

Two stripes of airphotos were flown by a minor aeroplane almost north-south across test area I. The cheapest way to acquire vertical exposures was to use a 'Hasselblad' 6x6 camera with 40 mm optic on colour infrared film - slides. Overlaps were 60% in flight direction and 20% side overlap.

A set of 5 airphotos has been scanned as transparencies on a flat bed scanner from 'Howtek' company. These airphotos have been geometrically corrected and resampled to UTM zone 32 coordinates with a ground resolution of 5x5 meters, determined by scanning resolution of 300 dpi which corresponds to 5.1 meters on ground. Geometric correction performed is not quite satisfying, as ground control points only could be selected from a 1:25.000 topographic map with an location accuracy around 15-25 meters.

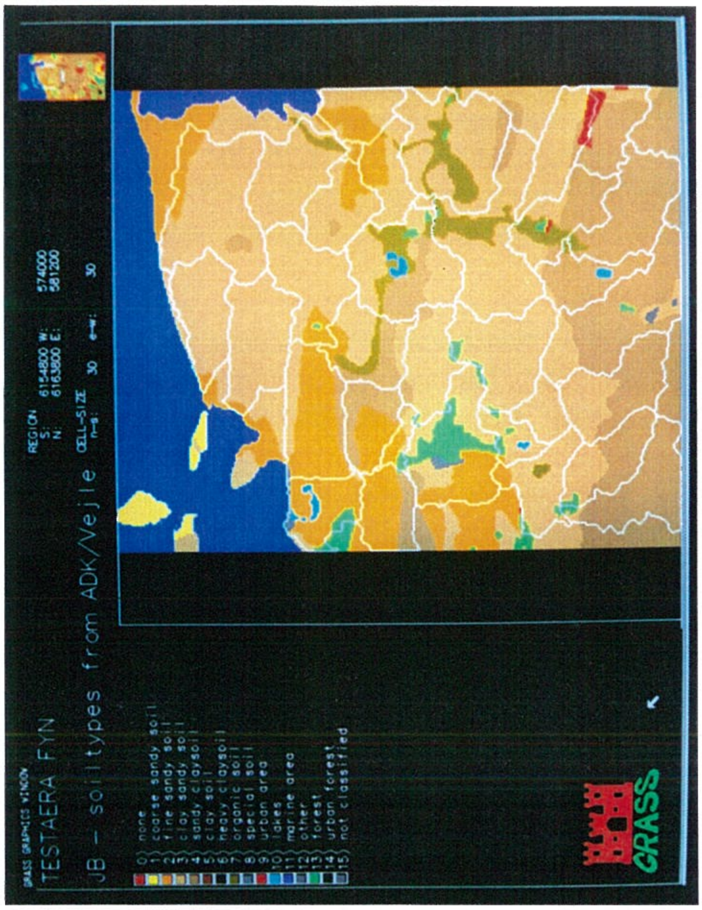
• Airphotos and small biotopes in test area II

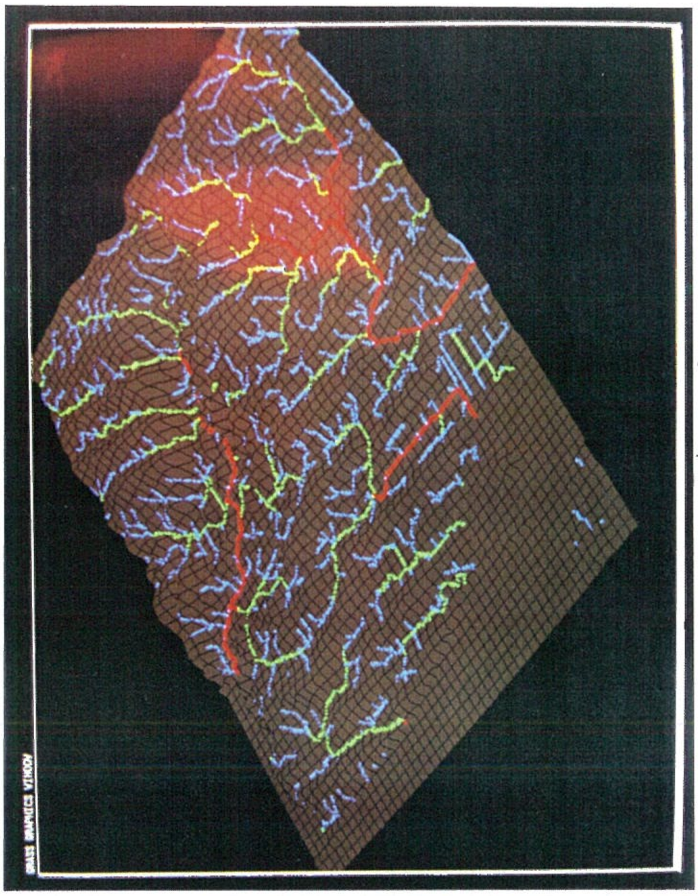
A description of how scanned airphotos may contribute to small biotope and marginal land mapping and monitoring will follow in the next chapter.

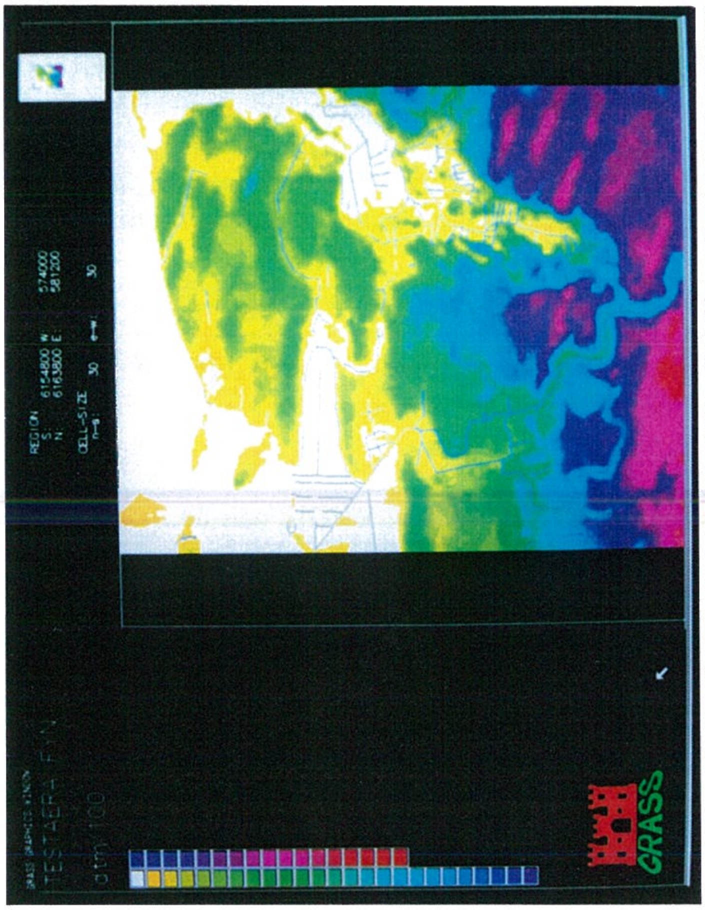
3.4 Examples of data analysis tasks

In this section a few examples will be given, to show how RUGIS can be used in landscape ecological analysis. Many other combinations of analysis task are possible, depending on demands from special applications. Furthermore, the database can be supplemented with other parameters, provided by digitising other maps, reading tabular information or by information extracted from Remote Sensing images and scanned airphotos via digital image analysis.

The plates on the following 4 pages are documentation too, showing how the system works and some general types of output that can be produced. Data analysis and mapping with respect to application of SGEOS data and scanned airphotos in small biotopes mapping will be presented in the next chapter.


GRASS GRAPHICS WINDOW
TESTAERA FYN
JB - soiltypes from ADK/Vejle
REGION S: 6154800 N: 6163800 W: 574000 E: 581200
CELL-SIZE n-s: 30 e-w: 30
0) none
1) coarse sandy soil
2) fine sandy soil
3) clay sandy soil
4) sandy claysoil
5) clay soil
6) heavy claysoil
7) organic soil
8) special soil
9) urban area
10) lakes
11) marine area
12) other
13) forest
14) urban forest
15) not classified
GRASS


GRASS GRAPHICS WINDOW


GRASS GRAPHICS WINDOW
TESTAERA FYN
dtm100
REGION S: 6154800 N: 6163800 W: 574000 E: 581200
CELL-SIZE n-s: 30 e-w: 30
GRASS

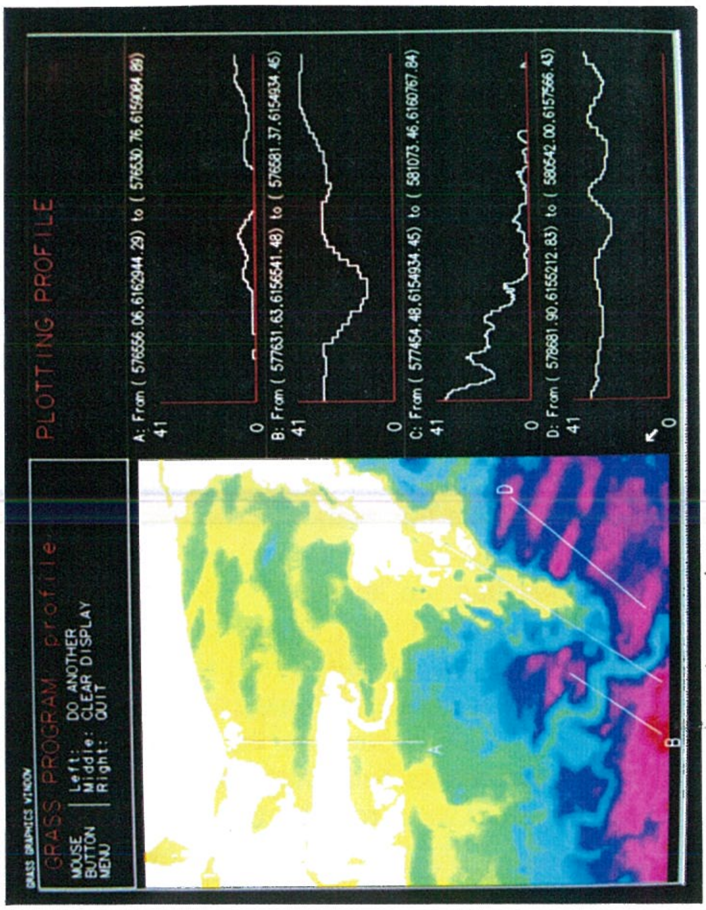

GRASS GRAPHICS WINDOW
GRASS PROGRAM profile
MOUSE BUTTON MENU
Left: DO ANOTHER
Middle: CLEAR DISPLAY
Right: QUIT
PLOTTING PROFILE
A: From (576556.06,6162944.29) to (576530.76,6159084.89)
B: From (577631.63,6156541.48) to (578581.37,6154934.45)
C: From (577454.48,6154934.45) to (581073.46,6160767.84)
D: From (578681.90,6155212.83) to (580642.00,6157566.43)
41
0
A
B
D

Plate 1.1:

Digital elevation model (DEM) of test area I (Funen). The legend to the left shows colour codings for height above sea level i meters, where reclaimed areas and areas below sea level area set to zero, represented by white. Furthermore, water courses digitized from an existing map are plotted in blue, read from a vector map.

The relationship between the terrain formes and water courses following the valleys becomes quite clear. This plate should be compared with plate 1.3 and 1.4, which are the result of a watershed analysis.

Plate 1.2:

A series of profiles have been defined on bases of the DEM, and are displayed on the right half of the screen. Up to four concurrent profiles can be created between two user depicted points. All positions are given in UTM system coordinates, zone 32. Another function makes it possible to extract profiles from a raster map, and save them for further analysis.

Profile A is a cross section (north-south) over one of the reclaimed areas, elevation is given in meter on the Y axes. B is a similar one across a valley from NE to SW, while profile C crosses the same valley and then approximately follows the easternmost reclaimed area. The last profile (D) cuts some of the drumline, shaped ridges in the eastern part of the test area, again from SW to NE like C.

Plate 1.3:

Soil classification map, received as a digital product from the ADK. In this case it has been rasterised to a 30 meter grid. Class 1 through 8 are soil texture types, while remaining classes represent different types of non agricultural and use / land cover.

The overlay map in white is a result of a watershed analysis run on the DEM. Catchment areas, drainage channels and accumulated water flow over the surface have been determined. Border lines shown as overlay in this plate represent drainage basins of at least 1 km^2, while all minor basins were considered too small to be exterior drainage basins. The threshold of $1km^2$ depends on the analysts subjective decision, and has been set in relation to total size of the area and the diversification of the landscape. Anyway, location of watersheds between major drainage channels draining larger areas should not be affected of this parameter.

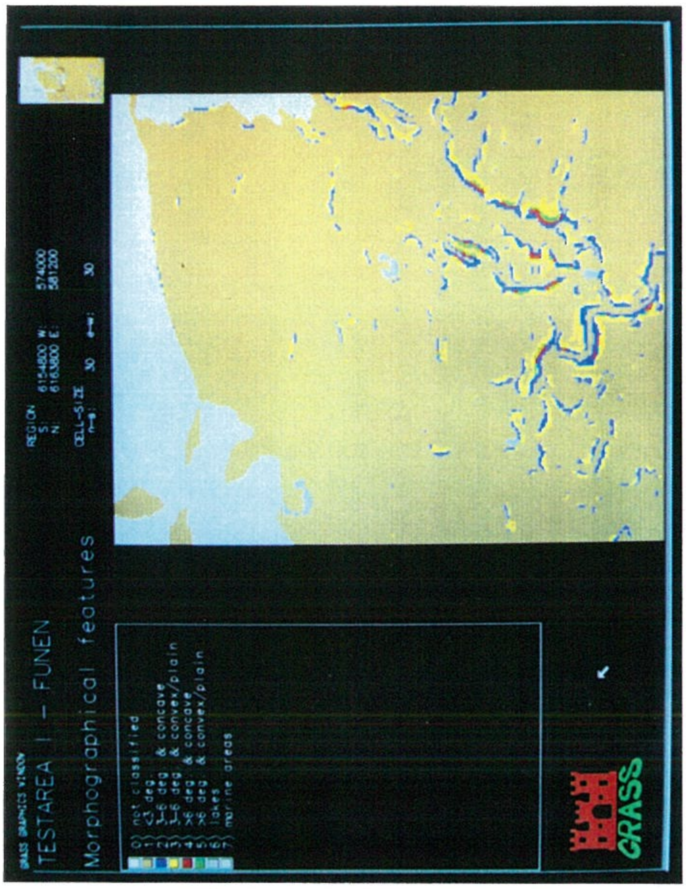
Plate 1.4:

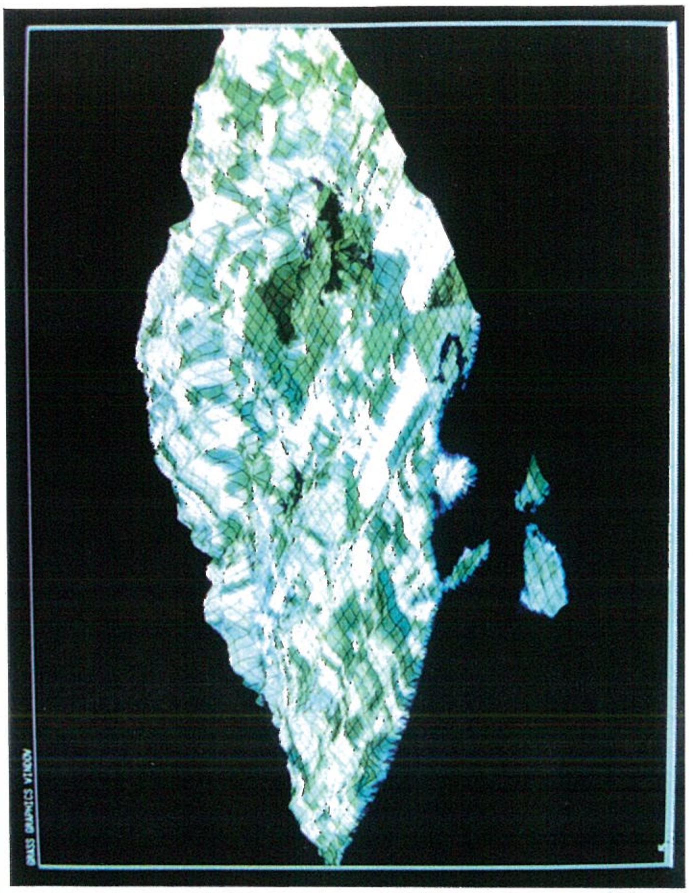
This map may be a little more easy to interpret than plate 1.3. As part of the watershed analysis, the accumulated surface runoff has been computed from the DEM. In this case the amount of runoff has just been set to 1 for each grid cell (size 30x30 meters = 0.09 ha), as rainfall is been assumed to be constant over the entire test area. For display purposes, the map has been draped over the DEM and values have been rescaled by $\log_{(1)}$, to give an accumulated runoff as follows:

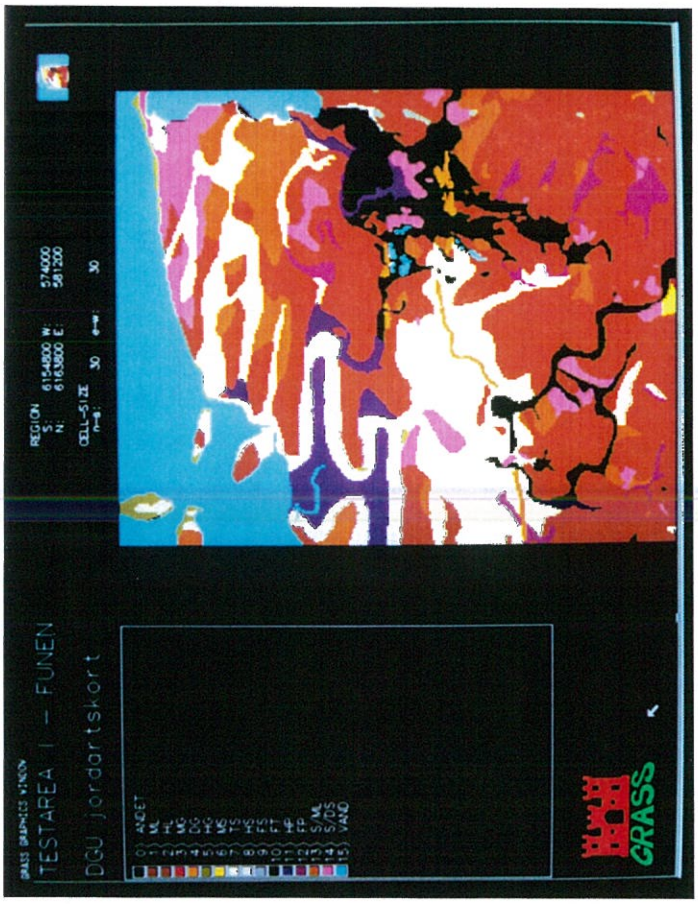
brown	= 0 to 1 ha	blue	= 1 to 10 ha
green	= 10 to 100 ha	red	> 100 ha

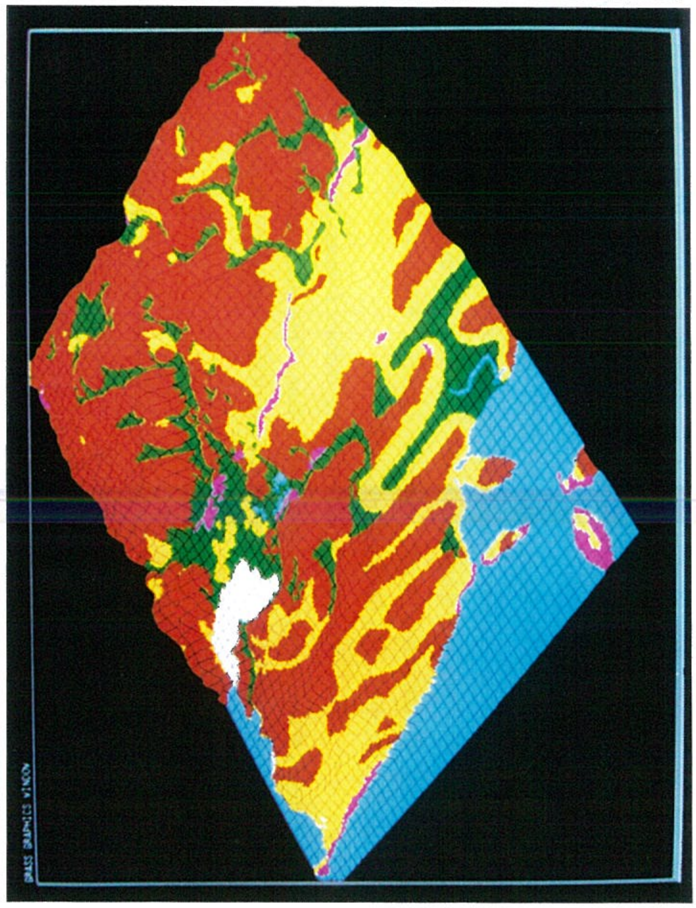
This could be modified for a larger area by including a map of rainfall distribution into the analysis. Moreover, the surface is treated as if it was a waterproof rubber sheet, i.e. no infiltration taking place. This may be corrected, if soil or geological maps can be used to derive an infiltration map.

Finally, the watershed analysis program has the ability to compute all the DEM-derivable para-meters necessary for input into USLE (Universal Soil Loss Equation) for erosion hazard prediction.


GRASS GRAPHICS WINDOW
TESTAREA I - FUNEN
Morphographical features
0) not classified
1) <3 deg
2) 3-6 deg & concave
3) 3-6 deg & convex/plain
4) >6 deg & concave
5) >6 deg & convex/plain
6) lakes
7) marine areas
REGION S: 6154800 W: 574000
N: 6163800 E: 581200
CELL-SIZE n-s: 30 e-w: 30
GRASS


GRASS GRAPHICS WINDOW


GRASS GRAPHICS WINDOW
TESTAREA I - FUNEN
DGU jordartskort
REGION S: 6154800 W: 574000
N: 6163800 E: 581200
CELL-SIZE n-s: 30 e-w: 30
GRASS


GRASS GRAPHICS WINDOW

<u>Plate 2.1:</u>

Plate 2.1 is a raster representation of the test areas geology 1 meter below surface, i.e. beneath the agriculturally layer usually cultivated.

Legend:

0	ANDET	not classified
1	ML	morainic clay
2	HL	salt water clay
3	MG	morainic coarse sand
4	DG	melting water coarse sand
5	HG	salt water coarse sand
6	MS	morainic sand
7	TS	fresh water sand (diluvium)
8	HT	salt water peat
9	FS	fresh water sand (alluvium)
10	FT	fresh water peat
11	HP	salt water mud
12	FP	fresh water mud
13	S/ML	ML overlain by sand
14	S/DS	DS overlain by sand
15	VAND	open water area

<u>Plate 2.2:</u>

This map has been derived from the subsurface geology map, by reclassifying it into 6 classes: clay (brown), sand (yellow), coarse sand (violet), peat & mud (green), open water (light blue) and unclassified areas (white). Overlay classes have been classified due to the lower material (S/ML as clay and S/DS as sand).

The resulting showing what could be called 'main types of sub-soils', has been draped over the digital elevation model (DEM). It displays quite nice clay located on ridges, while depressions predominantly are filled by sand. This is sometimes overlain by peat formed in areas with a high ground water level, or mud originating from marine deposits in reclaimed areas or freshwater lakes.

Last not least, coarse sand is found on top of the Grindløse esker as a special feature, crossing the area west-east.

<u>Plate 2.3:</u>

Map showing morphographic features within the test area. It has been derived as a combination of a slope map and a terrain shape map, both computed from the DEM.

The slope map showing terrain slope in degrees, computed from the surroundings of each grid cell. This provides an estimate of areas exposed to soil erosion, and areas difficult to cultivate by modern agricultural machinery. A terrain shape index has been computet to differentiate between concave and convex features in the landscape. In computation a 7x7 cell matrix was applied to each cell in the DEM, determining as an average wether the centre 5x5 cell were higher (=convex) / lower (=concave) than its border cells. Hereunder convex features tend to be soil erosion areas, while the concave ones more likely will be accumulation areas.

The resulting map is a combination and reclassification of these two maps, indicating 5 classes of morphographic features. It shows minor and steeper slopes, predominantly located along with the main valleys. The additional information on terrain shapes makes it possible to distinguish the convex (upper) part of a slope with increased erosion rise, from the concave (lower) part with reduced rise of erosion, or probably a zone of accumulation.

<u>Plate 2.4:</u>

The last plate has been produced from a false colour composite of the Landsat TM satellite image from 15th may 1988, using bands number 7,5,1 as red, green, blue respectively. Subsequent the image has been draped over the DEM to give a spatial impression of the landscape as seen from an aeroplane.

Finally, examples of tabular output from the system will be given below. The first example is a summary report of a single thematic map, see plate 2.1:

RASTER MAP CATEGORY REPORT   LOCATION: fyn   Mon Feb 17 12:13:24 1992

REGION		
	north: 6163800	east: 581200
	south: 6154800	west: 574000
	res: 30	res: 30

MASK:fk in stor, categories 0-10 12-15

MAP: DGU jordartskort (dgur in stor)

#	description (Category Information)	hectares	cell count	% cover
0	OTHER	108.18000	1202	1.95
1	ML	2521.17000	28013	45.49
2	HL	3.96000	44	0.07
3	MG	1.26000	14	0.02
4	DG	49.41000	549	0.89
5	HG	42.39000	471	0.76
6	MS	8.01000	89	0.14
7	TS	850.05000	9445	15.34
8	HS	274.95000	3055	4.96
9	FS	8.55000	95	0.15
10	FT	465.66000	5174	8.40
11	HP	259.56000	2884	4.68
12	FP	139.14000	1546	2.51
13	S/ML	429.48000	4772	7.75
14	S/DS	336.06000	3734	6.06
15	WATER	43.92000	488	0.79
TOTAL		5541.75000	61575	100.00

The second example shows a coincidence tabulation report between the reclassified subsurface geology map (see plate 2.2) and the soil texture classes from the soil classification map of Denmark (plate 1.3). Tabulation can be made in user specified units, where hectares have been chosen in this case. Other coincidence tabulations of interest could be soil types versus catchment areas, agricultural crops versus soil types or catchment areas,...

COINCIDENCE TABULATION REPORT

Location: fyn   Mapset: stor   Date: Tue Apr 21 15:00:36
Layer 1: dgu_csgp   -- DGU SUBSOIL 1 METER
Layer 2: fk   -- JB - soiltypes from ADK/Vejle DK
Mask: <dguru> in mapset <stor>
Units: hectares

Window: North: 6163800
West: 574000   East: 581200
South: 6154800

	cat#	dgu_csgp 1	2	3	4	Table Row Total w cat 0	w/o cat 0
f	0	17.19	0.00	0.27	1.08	18.54	18.54
k	1	2.34	15.39	25.38	0.00	43.11	43.11
	2	30.78	462.96	14.04	190.62	698.40	698.40
	3	1690.02	828.27	39.24	286.92	2844.45	2844.45
	4	1169.10	75.87	2.52	166.05	1413.54	1413.54
	7	19.08	4.50	2.97	184.86	211.41	211.41
	10	3.15	2.07	0.00	7.20	12.42	12.42
	11	1.80	4.23	4.77	0.00	10.80	10.80
	12	0.09	13.86	0.09	3.51	17.55	17.55
	13	22.86	74.70	8.55	24.12	130.23	130.23
Total with 0		2956.41	1481.85	97.83	864.36	5400.45	5400.45
w/o 0		2939.22	1481.85	97.56	863.28	5381.91	5381.91

4 Evaluation of SGEOS data and scanned airphotos in relation to marginal land mapping and monitoring

4.1 The GIS- and remote sensing-entrance ("top-down")

Within this programme a facility for semiautomatic delineation and presentation of small biotopes based on selected pixel-statistics has been developed (Christiansen and Nielsen 1991), and shall be described in the following. The developed facility has been tested by field work results, and a comparison of the program and other programs found in the literature has been carried out.

4.1.1 AREA: A programme for semiautomatic delineation of small biotopes

In short AREA is a programme that makes it possible to delineate areas of digital pictures based on a specified statistic. The program is written as a tool under the ERDAS image analysis system. To delineate areas the following procedures have to be carried out:

1. One pixel has to be pointed out as starting point.
2. A matrices for calculating of statistics has to be chosen (3x3, 5x5, 7x7, 9x9, 11x11 or 25x25 pixels)

Based on this the programme searches for all coherent pixels, which matches the statistics (Maximum-, minimum and mean-values and standard deviation), delineates the area (Polygon) and saves the data in three files (Statistics on bands, pixel-values and number and polygon-data.

It is possible to manipulate the delineation in two ways:
1. You can modify the statistics.
2. You can choose different search modes: "All around" or "Horizontal/Vertical". The "Horizontal/Vertical search" leaves out diagonal connected neighbour-pixel, thus giving a quicker but less accurate delineation. In the following all results refer to the "All-around" search mode.
3. You can specify a maximum number of pixels to terminate processing.

An overview of the structure of the programme is shown in appendix C.

4.1.2 Specification of the programme

To specify the demands to the developed facility the following list were made:

Functional demands:
- The programme shall be able to preform an automatic delineation of an area, which centre is pointed out with the mouse.
- It shall be possible to specify spectral informations, which shall be the basis for the delineation. These informations shall be calculated from the pixel pointed out. In this case the wanted informations are: Minimum-, maximum- and mean values and standard deviation for each of the channels of the image, you want to use for the delineation. After the calculation it must be possible to, either change the spectral informations, or approve the use of the calculated informations in the delineation. In connection with the change of the informations it shall be possible to calculate the minimum- and maximum-values from the mean value added a number of standard deviations, and it shall be possible to choose your own minimum- and maximum-values.
- It shall be possible to save the calculated spectral informations for use in other delineations.

- It shall be possible to specify a maximum area of distribution for the delineation. This will be useful in cases where the specified spectral information could delineate an area bigger than wanted.
- When the delineation is terminated a polygon shall be formed around the area. This polygon shall be saved in a form useable for other ERDAS programmes.
- For each polygon shall be counted the number of pixels (for area measurements) and the number of pixels for each value in the chosen channels. These informations shall be shown on the terminal and they shall be saved in a file to use for statistic calculations.

System dependent demands:
- The programme shall be developed under ERDAS in the language FLECS. FLECS is a superstructure to FORTRAN 77, which gives opportunities to call ERDAS toolkit programmes (programmed in FORTRAN). It is the goal to use FLECS as much as possible, thus avoiding the non user-friendly (due to the GOTO structure) ordinary FORTRAN programming. Furthermore this choice gives a possibility to evaluate the possibility to develop the entire program by the use of the FLECS structure and calls to ERDAS toolkit programmes.
- The programme shall use the opportunities, which ERDAS gives in form of use of keyboard and mouse in menu choices, and its advanced file management system.
- The delineation must be carried out as fast as possible, as the programme shall be used interactive with the user."

(Christiansen & Nielsen 1991 p. 24).

A large amount of work has been put into optimizing of the programme with respect to the time-use for the delineation. Especially in connection to the demand for each pixel to be coherent with an already approved pixel, a lot of time can be saved. Therefore as well a routine for the superior order of all the pixels, as a routine for the order of neighbouring visits specific for each pixel have been developed. This lead to almost a halving of the time-use for the delineation. (Christiansen & Nielsen 1991 p. 41)

4.1.3 Comparison to similar programmes

A theoretical comparison to two similar programmes have been carried out: SATFE (Buckheim) and the SEED command under ERDAS. Both these programmes are designed to classify areas from spectral images. The most interesting results from the comparison were:

- SATFEs use of variance and variance-increase
- The so called "linear growth" strategy in SATFE, which not (as the AREA program) is a simple approval strategy, but a selection of the most similar neighbouring pixel up to a specified limit.

The statistics of SATFE could easily be applied to the developed programme, thus giving further statistical informations on the delineated area. The search strategy mentioned above, could possible be used in the delineation of linear biotopes , at this time not developed for AREA.

4.1.4 The field test

To test the functions of AREA it has been compared to measurements in the field and results achieved by interactive digitising (The FIELD command in ERDAS). The field measurements were carried out in a 4 squarekilometres testarea near Tågerup north of Roskilde on Zealand, which also is a testarea for the Danish small biotopes project. To give an expression of the area and the measured biotopes a map is presented in figure 9.

The linear biotopes were paced out, while the patch biotopes furthermore were measured by estimating the angles. In general this method will give errors on 5 to 10% depending on the type and shape of the biotope.

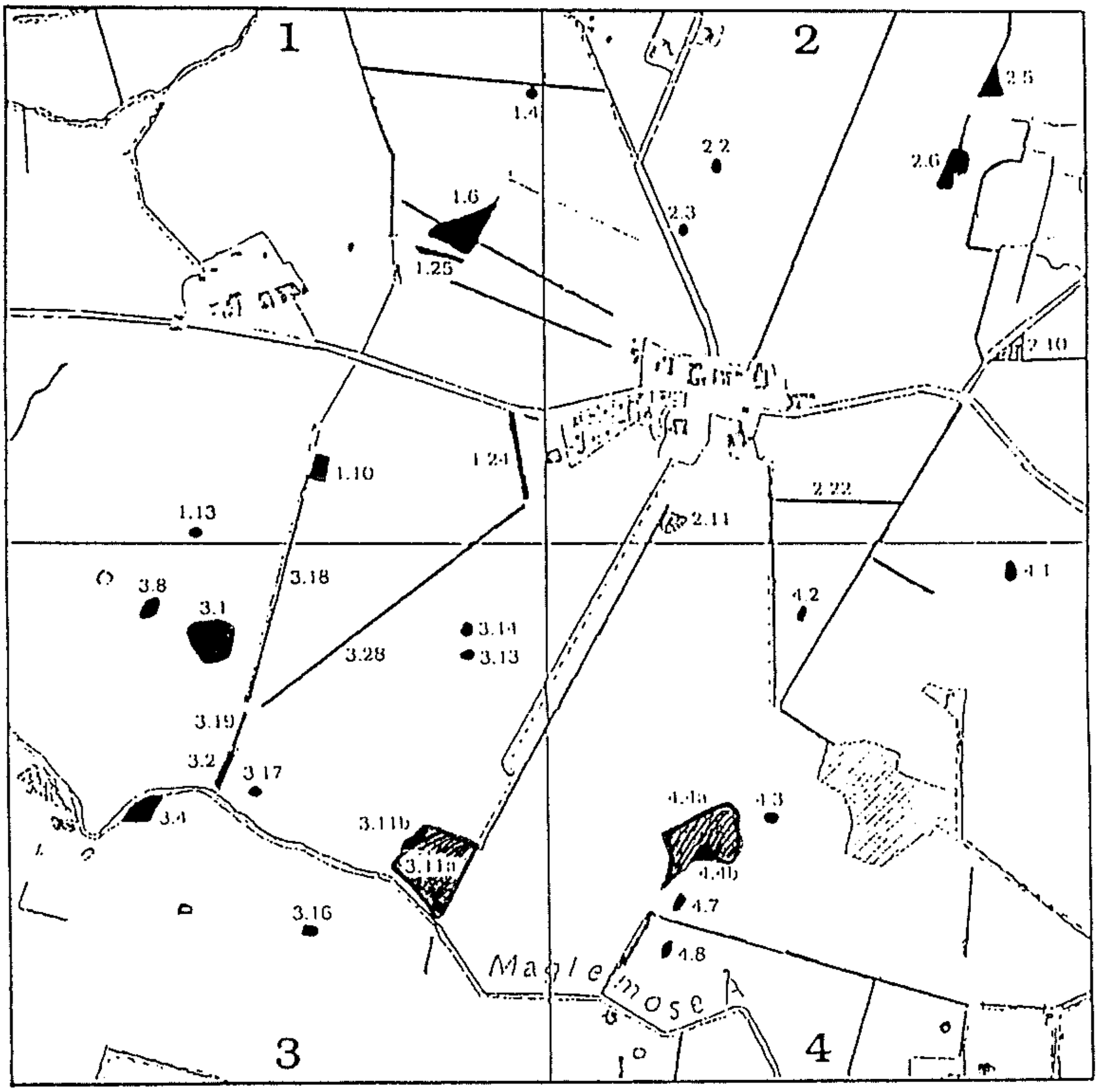


Figure 9: Map showing the test area II - 'Tågerup' - in the municipality of Gundsø/-Sealand, which is one of the small biotopes test areas. Each biotope has its unique number, displayed in figure 11 together with biotope type and size.

It must be stressed that the programme this far has not been developed to cope with linear biotopes. Future research will show if this is possible using some kind of directional oriented routines. In general it might not be possible with present resolutions in the images, due to the limited width of these biotoptypes (usually 0.5 to 4 meters). This problem is illustrated with the results achieved by interactive digitising, which show a tendency to overestimate the size of the biotopes.

- Datasources:

Two images have been used in the test of the programme:

1. A scanned black and white air photo 1:25000. spatial resolution 2x2 meters at ground.
2. A scanned colour air photo 1:25000, spatial resolution 1.25x1.25 meters at ground.

Different techniques have been used to improve the images for use in AREA. A short description and the major conclusions to the different techniques are given in figure 10. As it can be seen it has not been possible to improve the images to a degree, that could give better results in AREA. In the final tests the original colour air photo was therefore used. Further investigations on this area must be carried out, partly because others have shown better results, but mainly because of the connection between texture analysis and description of heterogeneity (see later).

- Results:

The results with the patch biotoptypes are much more promising. As it is seen in figure 11 it is not possible from this study to conclude finally on AREAs accuracy as no "truth" is established. Several errors can occur for the different methods, but some general tendencies can be drawn up from the results - off course taking in account, that the true sizes of the biotopes are not known.

One major consideration is that AREA has problems with heterogenous biotopes. Severe problems will occur, when the spectral signature of some parts of the biotope is close to the signature of the surrounding fields, or when minimum and maximum values of the spectral signatures ranges over the spectral signature of the surroundings:

For lake/ponds and maybe woodlots this seems to create a systematic underestimation of the sizes, corresponding with the results from interactive digitising.

For marvel pits and barrows the errors do not seem to be systematic. This might be caused by the type of heterogeneity - especially the grass vegetation/woody vegetation ratio.

In a general conclusion it must be stressed, that there is an element of subjectivity in both methods: In the interactive digitising in the visual interpretation of the air photos, in AREA in the specification of the statistics. On the basis of this, it must be expected, that an experienced user may be able to achieve better results, than those achieved in this project.

Data	Analyses	Methods	Results	Conclusions
Colour Photo	Spectral analysis	Principal Components	Informations: 1.component 93% 2. component 5% 3.component 1.5%	Not as accurate as with the use of the original 3-channel photo. No major advantages.
Colourphoto 1.PCA	Spatial analysis	Variance in 3x3 matrice	Accentuates major differences in the landscape.	Not usable in delineation of biotopes
B&W photo	Spatial analysis	Variance in 3x3 matrice	No results due to the high value of the standard deviation (56)	Not usable
B&W photo	Spatial analysis	3x3 High pass filter	Accentuates major differences in the landscape, but introduces more noise	No major advantages in the delineation of biotopes compared to the original photo.
B&W photo	Spatial analysis	5x5 High pass filter	As for 3x3 filter but introduces less noise	No major advantages in the delineation of biotopes compared to the original photo.
B&W photo	Spatial analysis	5x5 Sum filter	Accentuates major differences as the above mentioned filters, but seems to focus on natural differences.	No major advantages in the delineation of biotopes compared to the original photo.

Figure 10: Different methods of improving scanned air photos for use with the AREA programme. None of the methods applied has been found to improve the photos considerably. It must be emphasised that this conclusion concerns the small biotopes approach, while agricultural units and other types of land cover seem to be more promising.

Biotop type and number \ Method	Interactive digitizing	AREA	Field work =Index 100
	Index	Index	m2
Field track 1.24	114	*	614
Field divide 3.18	188	*	1002
Field divide 3.19	224	*	504
Average field divides	206	*	
Hedgerow 3.28	121	*	1939
Hedgerow 2.22	110	*	510
Average hedgerows	115	*	
Ditch 1.25	91	*	920
Average linear biotopes	141	*	
Marvel pit 2.2	72	101	470
Marvel pit 3.16	92	90	553
Marvel pit 4.1	79	102	381
Average Marvel pits	81	98	
Lake/Pond 3.4	62	60	2662
Lake/Pond 3.17	91	84	2228
Average lake/ponds	77	72	
Bog 1.6	63	94	10987
Bog 1.10	78	179	1872
Bog 2.5	112	*	1587
Bog 2.6	114	*	410
Bog 3.1	101	123	6335
Bog 3.8	91	96	828
Bog 4.2	111	*	237
Bog 4.7	118	118	1099
Average Bogs	99	122	
Barrow 1.4	128	130	234
Barrow 1.13	134	168	335
Barrow 2.3	117	66	176
Barrow 3.13	104	70	283
Barrow 3.14	104	97	580
Barrow 4.3	98	85	125
Barrow 4.8	118	112	248
Average Barrows	115	104	
Woodlot 2.10	100	*	1271
Woodlot 3.2	76	*	1992
Woodlot 3.11ab	97	77	16464
Average Woodlots	91	77	
Average patch biotopes	98	103	

Figure 11: Indices of measurements of sizes for different biotope types with area and by interactive digitizing on the screen. For each biotope the index is set to 100 = field measurement in 1990. This should not be taken as the absolute truth, but only as an arbitrarily chosen reference, as these field determinations may be erroneous too. The biotope numbers refer to figure 9.

4.1.6 Monitoring of biotopes with AREA

Two aspects must be taken in consideration in an evaluation of the possibilities to use AREA in monitoring of small biotopes:

- The possibility of detection of all types of biotopes.
- The possibility to detect changes in the individual biotopes in time.

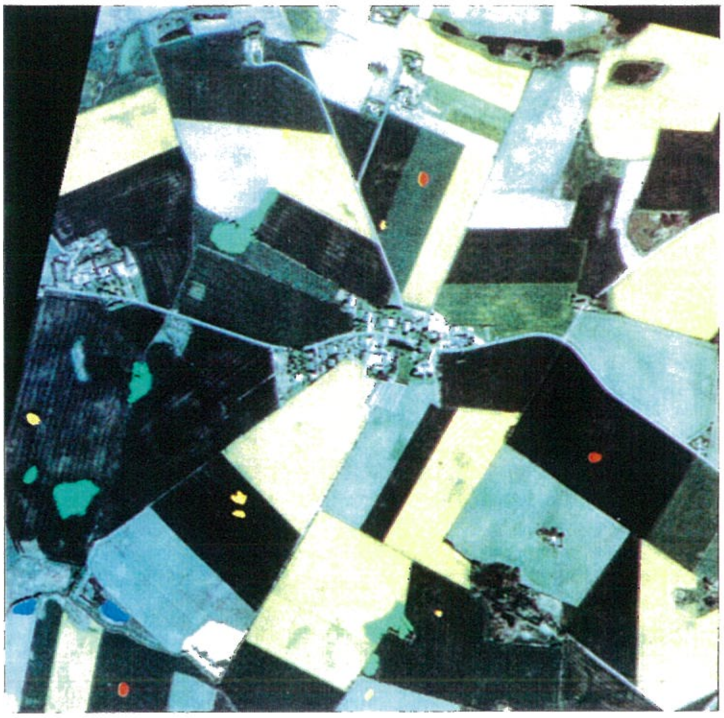
Basically the first point is not related to AREA, but to the possibilities to visually detect the biotopes. Based on the experiences in this project the conclusion is, that it is not possible to detect all linear biotopes on images with a resolution of 1.25x1.25 meters. For patch biotopes it seems clear, that it is possible to detect almost 100% of the biotopes - but the project has not solved the problem of typifying the biotopes from spectral values. Some attempts to delineate biotopes of the same type using the same basic statistics have not been successful (See plates 3.1 and 3.2)

In monitoring the changes in time, two things could be interesting in connection with image analysis.

- Changes in size of the biotopes.
- Changes in type of the biotopes.
- Changes in the heterogeneity of the biotopes.

The measurements of biotope-sizes with AREA in the present project leaves no clear conclusions, whether it will be possible to use the programme for monitoring biotopes in the future. On the present stage the errors are too big to fulfil the demands of the Danish biotope project. Up till now it has been the practice to base the estimations of size on a subjective evaluation of qualitative changes. That is, a measurement has only been carried out if a change was visually detectable in the field. The methods used (the biotopes have been paced out/measured on maps) in general gives variations on 5-10% depending on the shape of the biotope from one period to another. This is very close to the not-acceptable, and higher values of errors cannot be accepted. It has to be taken in account that measurements in the field using Global Positioning Systems can supply a much higher accuracy: $\pm$ 4 meters on linear elements regardless of size. GPS must therefore at present be the best alternative in monitoring changes in the size of small biotopes.

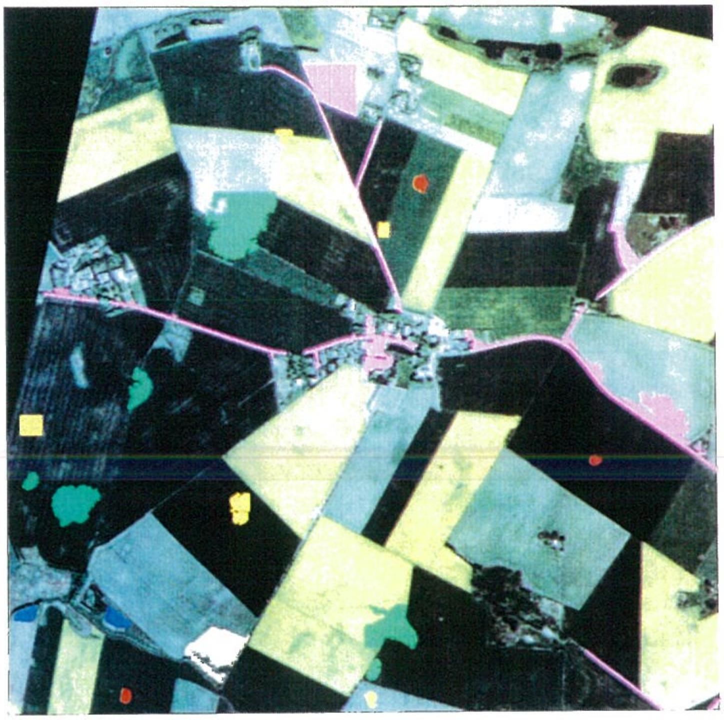
As mentioned above it has not been possible to delineate biotopes of the same type using the same statistics. A monitoring of possible temporal changes in biotope type over a time interval of i.e. 5 years would furthermore be blurred by changes in the spectral reflectance due to changing illumination. These may be caused by varying weather and/or seasons of the year. It has not been a goal of this project to evaluate this problem, but based on the above mentioned the prospects are not very good.



Legend for polygons

green: bogs
blue: lake/pond
yellow: barrows
beige: woodlots
red: marvel pits

Plate 3.1: Digital colour airphoto of Tågerup (test area II), showing polygons for patch biotopes delineated by the developed programm AREA.



Legend for polygons

green: bogs
blue: lake/pond
yellow: barrows
beige: woodlots
red: marvel pits
violet: roads and field tracks

Plate 3.2: Same as plate 3.1, but all polygons for the same type of patch biotopes have been delineated with a type specific statistic. The resulting over estimation of biotope areas emphasizes the necessity to specify individual statistics for each biotope.

It has been a goal of the latest small biotope investigations to map changes in the patchy biotopes heterogeneity. This has been done through an internal tessera classification, giving information on the proportions of woody vegetation, grass vegetation, reed vegetation and open water. AREA gives two possibilities to monitor changes in this heterogeneity:

- Measurements of the tesseras.
- By using the statistics for delineation to describe the heterogeneity.

Two problems occur by measuring the tesseras: The same inaccuracy as by measuring the biotopes will be the result, and the problems with the resolution of the images will be more frequent. In general measuring the tesseras have not been possible within the frames of this project, but the problem is more related to the resolution of the images, than to AREA.

The statistics in AREA might be used to describe the heterogeneity of the biotopes. The statistics include minimum- and maximum-values of pixel-values plus variance and standard deviation of these values. With these values it is not possible to distinguish between different parts of the biotopes (= the tesseras), which means, that the statistics can be used to describe only the heterogeneity of relatively homogeneous units. The use of AREAs statistics in monitoring changes is further more problematic, because they are used in the delineation of the biotopes. Changes in the heterogeneity will foremost be recognised as changes in the size of the biotop. An additional program WEED has been developed to classify the biotopes delineated in AREA, but at the present stage it is a mere simplification of the statistics in AREA. At the present stage it must therefore be concluded, that AREA cannot be used to monitor changes in the biotopes heterogeneity.

4.1.7 Conclusion

This project must be described as very preliminary with respect to the achieved results.

- Detection of small biotopes has not been improved remarkably.
- Delineation of small biotopes is not developed to an accuracy usable in monitoring.

In the following figure 12 the possibilities of delineation with AREA are summarized. The problems in the delineation can be described in tree categories:

X: The delineation can be improved to an acceptable level by an experienced user.

●: The delineation methods of handling heterogeneous biotopes must be improved.

*: The most important problem is the resolution of the images, but development of directional oriented routines might improve the delineation.

Future research should try to improve the possibilities of monitoring small biotopes using remotely sensed data including scanned air photos. As it will be pointed out in chapter 4.2. however, detailed field studies still will be important for several reasons. To the reasons mentioned there, the present part of the programme adds the problems in monitoring the heterogeneity of the biotopes.

Landscapelement	Can be delineated	Can possibly be delineated	Cannot be delineated
Fields	X		
Lakes and ponds	X		
Barrows	X		
Bogs		•	
Woodlots		•	
Game plantations			•
Paved roads	X		
Field tracks			*
Hedgerows			*
Field divides			*
Ditches			*

Figure 12: Possibilities for delineation of different landscape elements with the program AREA, which has been developed under this project (Christiansen and Nielsen 1991).

4.1.8 Future research

To apply semiautomatic delineation methods to the Danish small biotopes project in its present form, the following must be done:

- Other delineation-methods must be applied to linear biotopes.
- Experiments must be carried out with images with a higher resolution than 1.25x1.25 meters per pixel, to improve the accuracy of the size-measurements.

In the following field the developed facility could improve the Danish small biotope project:

- Description of the heterogeneity of patchy biotopes. The statistics in AREA are a step towards describing heterogeneity from digital data. It should be possible to add cluster- and texture-analysis to the biotopes delineated by AREA.

AREA could be used in the field-work-entrance described in part 4.2. Thus the program had to be modified to give possibilities to edit the polygons.

A third and obvious step is to apply AREA to other research- and monitoring-programmes. A possibility is monitoring in connection to the new Danish environmental conservation law. In this bogs larger than 2500 m^2 and lake/ponds larger than 100 m^2 are protected and a monitoring programme including the use of AREA could be useful for the maintenance of the restrictions. Especially the lake/ponds, which are defined by the size of the open water could be monitored satisfactory using AREA.

4.2.The small-biotope field-work-entrance ("bottom-up")

To give a better understanding of the approach and the proposal given for an integration of SGEOS-data and scanned air photo in the future monitoring system, the evaluation will be introduced by a presentation of the project, it's background and perspectives.

4.2.1. Small biotopes and their growing importance in modern society

Small biotopes have for a decade mostly been a generic term for all types of small uncultivated areas, that serves as habitats for wildlife within the agricultural landscape: Hedges, roadside verges, drainage ditches, small brooks, bogs, marvel pits, natural ponds, thickets and prehistoric barrows are examples.

The interest in small biotopes and similar ecological networks, their geographical composition, structure and development, has developed during the 70ties and 80ties in many industrialized countries (Baudry 1984, Burel 1992, Ihse 1984, Ruthsatz & Haber 1982, Schmel & Engelmaier 1982, Rambousková 1989).

The motivation behind these studies has generally been twofold:

1. The development of theories within landscape-ecology and especially within the so-called island-bio-geography, generally indicating that
   - the size, shape and arrangement of areas composing a landscape are important to the function and persistence of each individual area and/or the landscape as a whole, and
   - connections between similar areas (e.g. non-cultivated land) increase the interactions between them, have given important scientific motives for further studies of the geographical structure and development of the biotopes and the land use, that they are embedded in.

2. The relevance of this scientific progress has been strongly actualized through the development within agricultural technology, that has given rise to a rapid decline in the number, density and variability of the small biotopes in many agricultural landscapes, especially where this development has been attended by a parallel concentration of ownership through growing size of holdings (see Meeüs et.al 1988).

Conceptually the small biotopes can be seen as a network that is embedded in a matrix of cultivated fields as defined by (Forman & Godron, 1986). But as a matter of fact they can be related to a much broader perspective as material forms for spots and lines, that serves as notes, networks, transition zones and delineators in the local environment of natural and human systems. So, in analogy to the small biotopes of agricultural landscapes, similar systems of networks are seen in the urban environment, where the matrix is replaced by buildings, squares and other areas sealed up with different kinds of pavement, and the network consisting of streets, hedges and adjacent cover of grass or herbs, canals, ramparts, parks, gardens, and other types of green belts.

Typically such small biotopes have historical inherited multiple functions within both nature and society, and this has to be taken into consideration by their removal or change: So, removal of a drainage ditch might not only be a disaster for the organisms living in it, but also endanger species of other biotopes if the pond has been serving as a corridor for the dispersal of certain species.The ditch is however also important by draining the surroundings and cannot just be cancelled without ensuring this function e.g. through laying down drainage pipes.Such a lowering of the drainage level might sometimes presuppose an artificial pumping system, that has to be maintained. The ditch might in many cases be placed in the boundary between to properties, thus having a social function, that has to be represented in one or another way. A related hedgerow and crop-free zone might pick up some of the surplus nutrients, and this function might be combined with a necessary presence of a field road. The hedgerow might have an additional function as windbreak, that would have to be replaced in the vicinity by removal, or if not, it might have a limiting influence on the agricultural land use possible.

So, even if the concept of small biotopes are most often defined from a biocentric point of view, it is closely related to the abiotic components of the landscape (soil, geomorphology, hydrology and the natural flow of matter, microclimate), as well as to cultural factors (transportation routes, way of property and land register), as well as their history.

This integration of different forms and functions makes it necessary to study the small biotopes both from a nature scientific, as well as from a social, economic and historical point of view. It has also important implications for the use of SGEOS-data and scanned airphotos as a part of a future registration and monitoring system, as will be seen later.

In Denmark studies of the structure and dynamics of small biotopes started for more than 10 years ago. The methodology was developed in the end of the 70ties and a comprehensive study in 13 2x2 km test areas was carried out in 1981. Basically this campaign consisted of a detailed field registration of all line-biotopes and patch-biotopes less than 2 ha within the open land. Interviews with farmers concerning general agricultural conditions, the functions of the small biotopes and future plans for their biotopes was added an historical analysis of the development of small biotopes in 5 of the test areas, based on maps and air photo interpretation, were also included.

The field campaign has been repeated in 1991, 10 years after: The field methods used has been almost the same, but the number of areas has been increased to 32, covering all parts of Denmark. A general land-use mapping and a survey of basic heterogeneous landscape units in all test areas has been added, and the way and geographical precision of data-storage has been improved considerably.

The biotope registration and land-use-mapping has been done during the summer and the interviews in the autumn. A relational database based on Oracle /SQL has been created to handle the data and adjusted especially to fulfil the needs for spatial analysis.

4.2.2 Classification of small biotopes and changing scopes of the investigations

When the project started at the end of the 70ties, the scope was to give empirical information on the structure (composition and geographical pattern) and development of the small uncultivated landscape elements within the agricultural landscape, and the processes behind.

Much effort was put into developing a reproducible classification and field registration method to ensure that changes in the composition and pattern could be registered with a high reliability .The classification of small biotopes use vernacular names , but the types of biotopes are defined more strictly. A hierarchical structure of the biotope types, used for different levels of statistical generalization is shown in figure 13.

The classification system is however not hierarchical based (except the division into patch biotopes and linear biotopes) and certain types are difficult to put into this principle scheme.

The dynamics of pattern of small biotopes were in focus already in the investigations in 1981. The classification system and field methods developed could however be evaluated only roughly for dynamic purposes at that time, since the historical development was exclusively based on map and air photo interpretation. as described later on. These are sources that only to a limited degree can fulfil the ecologically oriented classification system.

In 1986 however, the registration method was used as a main source of information on status and development of marginal land within the intensively used Weichsel moraine landscapes in Denmark. Here, the small biotopes can be seen as almost the only area resource for agricultural expansion; and management as well as re- and new-establishment of small biotopes will be a relatively important part of a marginalization within these areas. Buffering zones along and around existing biotopes could be an important tool for a marginalization process, too.

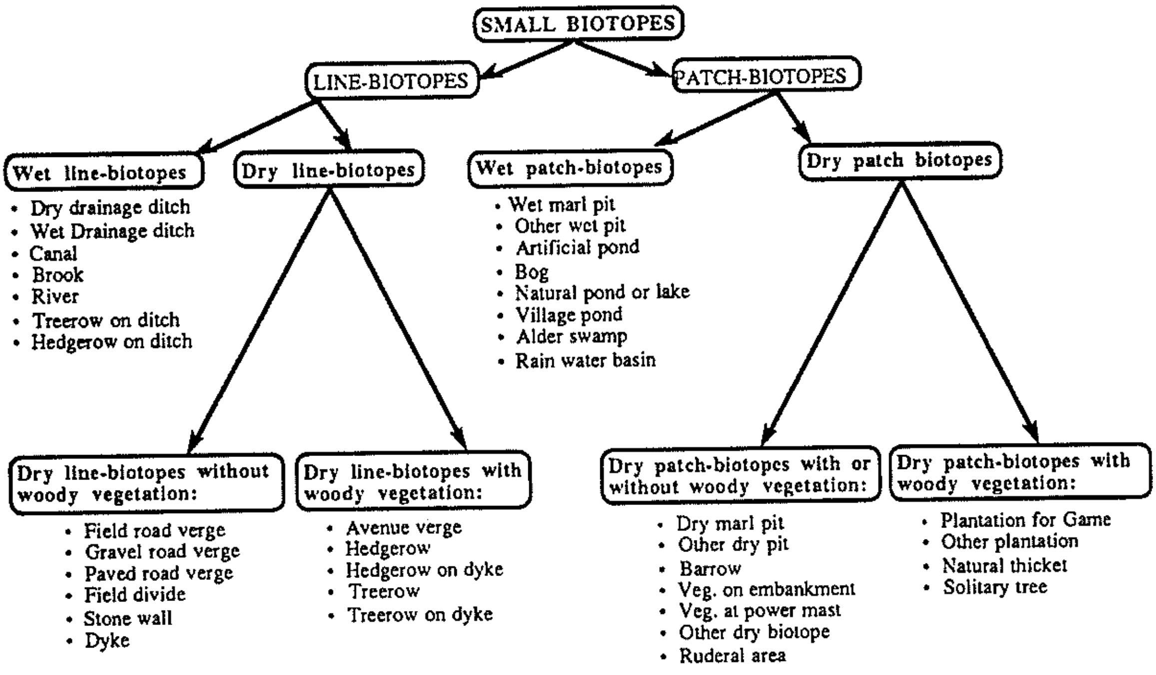


Figure 13: Main types of small biotopes used in the Danish small Biotope Studies.

A somewhat simplified registration of small biotopes in the 13 test areas plus another 13 new areas of eastern Jutland, was carried out. These investigations proved, that the development of the small biotopes can be a sensitive indicator for the intensification / extensification of agricultural land-use (Agger & Brandt, 1988). But it also proved, that it preferably should be linked closely to a parallel incorporation of information on the development of the general land-use, such as changes in the proportion of tilled land to woodland, grassland, wetland, fallow and build-up-areas.

The 1991 campaign is related to a somewhat new scope: Namely to the general monitoring of the wildlife and habitats in the agricultural landscapes: In 1987 the registration method was incorporated in a guide on registration of small biotopes to be used by the Danish counties for surveys within typical agricultural areas of the counties (Tvevad, 1988) The on-going campaign has been carried out in cooperation with the Ministry of Environment to serve as a part of the general national monitoring programme.

Wildlife is heavily dependant on the small uncultivated habitats within and between the fields. This is certainly true in a country like Denmark where 2/3 of the total area is intensively cultivated. Therefore the monitoring of the development of the pattern of small biotopes is a useful indicator for the development of wildlife. But it is also reasonable to monitor the pattern for its influence on the ecological processes and its value for the scenery of the landscape.

Monitoring the development of small biotopes have therefore been included in the farsighted national monitoring programme in Denmark (Agger, 1991). This is added to monitoring programmes for other (larger) types of habitats in and outside the agricultural landscapes and selected species or group of animal and plant species.

The purpose of the national programme is
- to supply the society with comprehensive and up-to-date knowledge on the state of the environment,
- to serve as a warning system and
- to make evaluation of the effect of former actions both in the case where these have had a management objective and also where the purpose has been something else but where impacts as a side effects might be seen in the environment.

The biotope project should fulfil all three purposes. It has given a description of the general trends. It has supplied us with quantitative estimates concerning which types of habitats that are most threatened (Agger & Brandt, 1988). And by now being repeated it forms a base on which the effectiveness of recent management can be evaluated.

4.2.3 The use of air photos in the small biotope investigations

Air photos have been extensively used by the mapping within the small biotope project:
- first of all by the localization of the majority of biotopes not given at the topographical maps.
- by the estimation of the area of patch biotopes greater than about 500 m^2.
- by the mapping of general land use (e.g. to give a statistical frame of reference for the calculation of small biotope densities), and
- by the delineation of agricultural land use units.

For historical studies of the small biotopes in some of the test areas, air photo interpretation has been used to determine the type and extent of biotopes since 1954. This has in reality only been possible because the historical photos could be compared with field data and more recent photos, that could facilitate the interpretation. Their are however many problems with an interpretation only based on air photos:

- The width of linear biotopes and the area of small areal biotopes less than 50 m^2 cannot be estimated.
- The most common small biotope: Field divides, cannot be clearly separated from drainage ditches and low dykes.
- The tree vegetation cover tends to be underestimated, since tree cover under 3 meter high is difficult to separate from other sorts of vegetation.
- The determination of type and internal differentiation can be very difficult to estimate, especially for the linear and smaller patch biotopes.

For several reasons we still consider it for both necessary and important to ensure a monitoring procedure based on detailed field surveys:

1. They will serve as necessary ground truth for any remote sensed monitoring.
2. They can detect the total network of biotopes, and the whole range of biotope types, including types, that cannot be registered by remote sensing, such as narrow field divides, small ditches, solitary trees or vegetation under high-power electricity-masts: Detection of these types of tiny biotopes can be important for two reasons: some of them can be fine indicators of general tendencies in the biotope pattern due to agricultural changes, and secondly they will be important to include for a characterization of the quality of the total biotope pattern. Considered generally as low quality patches and corridors they might be better than nothing, but however also have a negative influence on the size of metapopulations, as indicated by the simulation models set up by (Henein & Merriam, 1990).
3. Many studies on the dynamics of the biotope structure are based on time-series of maps or airphotos of a relatively long time-span, that gives a rather good validity although the sources are inaccurate or subject to different interpretations. But a monitoring of the general development for a time interval of 5 or 10 years within a limited number of test areas has to be based on a rather detailed and valid registration system to minimize the influence of technical errors or misinterpretations. With an average of about 200 small biotopes per test area, even a 1% annual change means changes in only 10 biotopes over a 5 years period. With very different tendencies for the many different biotope types, it does not give much room for errors and misinterpretations if a reliable type-differentiated quantitative statistics shall be obtained.
4. Detailed fieldwork give good opportunities to come into contact with the farmers, thereby giving a lot of important information, that easily are neglected by a pure remote sensing based monitoring procedure done by environmental planners and managers. This goes especially for information on the functions and dynamics of the small biotopes in relation to the development of the agricultural system. The involvement of farmers in the ecological planning and management of agricultural landscapes are often crucial (Luz, 1991), and since a monitoring system is to be seen as an information base for future action, the involvement of farmers should not be omitted at the monitoring level.

4.2.4 A framework for integration of SGEOS-data and scanned airphotos in a future monitoring system

By the preparation of the 1991-survey we have focused on a development of GIS-tools to serve datamanipulation for landscape-ecological analysis of small biotope data, since it was the weakest point of the registration system set up in 1981.

The way of data-collection has however not been altered very much since the 1981-survey. Almost the same registration forms has been used for the field registration and interviews with the farmers (concerning the agricultural and ownership conditions and the functions of the biotopes), the most important changes being a complete mapping of the agricultural land use, and a preparation for a complete digitising of all geo-related data.

This registration implies in average filling out about 50 small -biotope registration forms per km^2, a precise delineation of the biotopes on a draft map in 1:10 000 - with details concerning the inner differentiation (main categories: tree cover, herb cover, reedmarsh, open water, build up and paved area) given on a sketch on the registration form, another draft map with the land use survey, and a third one giving geographical information concerning cadastral relations.

About 5 interviews per km^2 concerning the general information on agriculture and on the functions of the biotopes within the holding, are also saved in special forms.

Although the coding of all the forms from the field registrations and interviews has been facilitated through forms-completion as a very user-friendly front end, it is still a complicated and time-consuming process:

This is so because many considerations concerning an appropriate classification, mapping and characterization of the related attributes has to be dealt with, and because many mistakes and omissions are first unfolded during the attribute coding process or the digitalization, thus giving rise to much editing, taking place long away from the locality and often with a time-lag that adds to the problems and the unreliability of the interpretation.

In the foregoing we have argued against a pure remote sensing-based monitoring of small biotopes. This however does not mean that SGEOS images cannot be of use by mapping of small biotopes. In fact the opposite is the case. With SGEOS-data and digitized airphotos it should be possible to speed up the registration and secure a better reliability by developing an on-side digitalization and attribute-coding. The possibilities of a systematic investigation of the relation between spectral and textual information and the mapping and characterization of small biotopes would also be improved considerably by in integration of Remote Sensing data in the registration procedure.

Our research on using Landsat TM for the delineation of small biotopes has not been successful (see report from contract no. 3734-89-06 ED ISP DK). But recent research by Goossens et.al. (1991). indicates some possibilities by using SPOT multispectral images. By edge-enhancement they have been able to detect different types of linear elements due to their direct or indirect effects on the spectral signature (generally as "mixels") For satellite image interpretation they introduce the term 'land block', defined as a surface area with the same land use, surrounded by at least three linear elements. These landblocks can be detected unmistakably, if they are more than 3 ha,when the length exceeds 300 m, or when the width exceed 120 m. And they cannot be detected if they are less than 1,2 ha, have a length less than 130 m or a width less than 80

m. These results are very promising from our point of view: Since the land use of contemporary Danish agriculture is very "patchy" due to recent reintroduction of a regular crop rotation, such land blocks will delineate the vast majority of linear biotopes even if their type cannot be detected. Using panchromatic SPOT-images will certainly give an even better background for the delineation of linear biotopes.

A future monitoring system could without doubt rely much more on an integrated use of SGEOS-data, scanned airphotos and topographical/cadastral information within the field survey process (See figure 14).

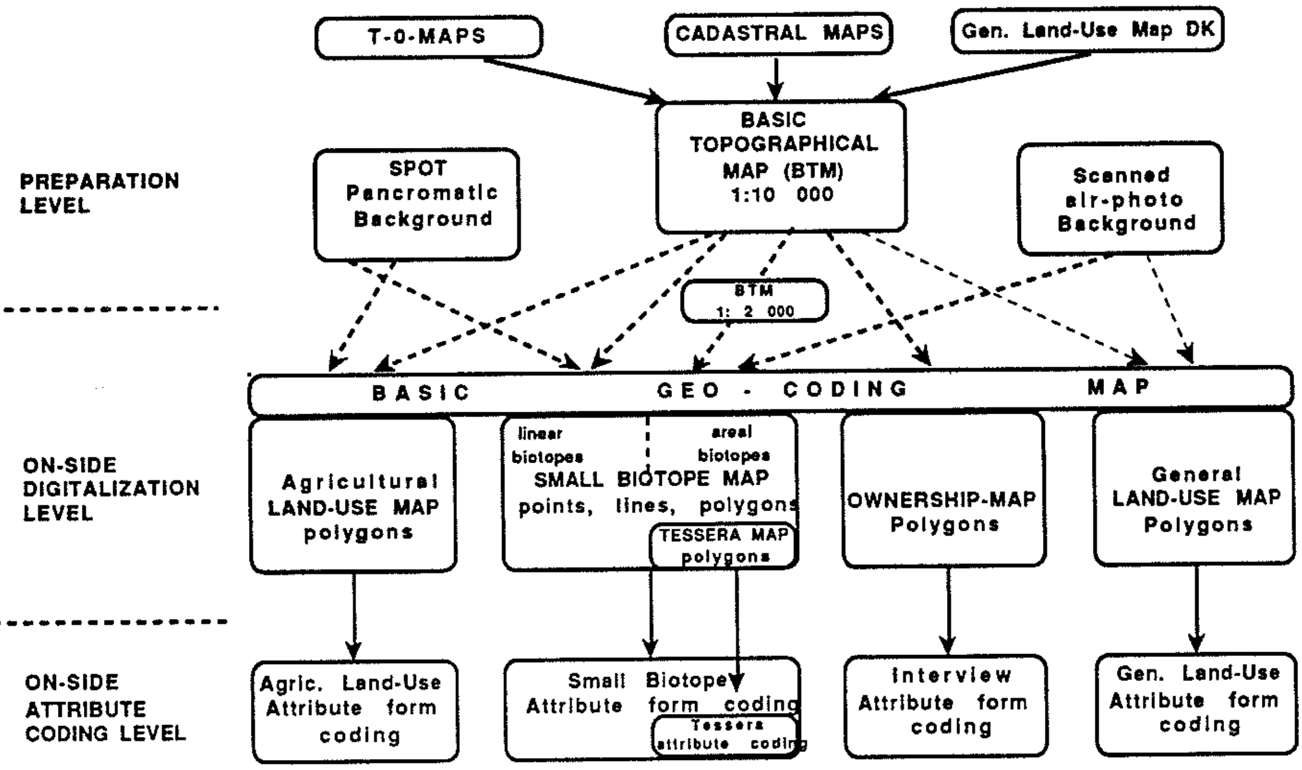


Figure 14: A framework for an SGEOS-aided interactive on-side registration of small biotopes and related data.

This will require a powerful laptop with a high-quality grey-tone or colour screen, that can make an integration of the attribute-coding and digitalization possible through the following steps:

1. The topographical base should be provided beforehand in scale 1:10 000 through either digital topographical maps (in Denmark the so-called T-0-maps), the digitized cadastral maps, the general land use map (being carried out in Vejle) or a combination of the three sources. Cadastral maps are especially suited, since our investigations shows that in average 80% of the small biotopes are located in relation to ownership boundaries. It should be possible to change the scale to 1:2000 for the mapping of the internal differentiation of the biotopes,.

2. An up-to-date SPOT panchromatic image as well as a scanned airphotos preferably not more than 5 years old should be available as backgrounds to support the direct geo-coding of biotopes in the field. These backgrounds should be adjustable to the basic map at the local level. Due to the edge-effect most linear biotopes recognized in the field will be geographical locatable on the SPOT scene, although no or very little spectral information concerning the biotope might be available. In the case, the linear feature is not linkable to existing lines on the basic map, it should be digitized directly on the SPOT background. The SPOT-background will also be very useful to add missing lines necessary for the mapping of the agricultural land use.

By patch biotopes the use of scanned airphotos will in most cases be useful for a digitalization, even if they are not up-to-date. Here it should be possible to blow up into 1:2000 to allow for a reasonable precise mapping of the biotope and the internal differentiation in some major tesseras within it (see part 2.b). The precision needed is relative, not absolute, but it should also be possible to fit the SPOT-image locally to the geo-coding map to catch pixel-statistics for the biotopes. In cases, where larger changes in relation to the air photo can be observed, the SPOT-background might be useful to consult. This internal tessera-mapping should be optional, with the alternative to leave for the attribute characterization a crude areal percentage of the different tessera-types within the biotope. This might generally be the practical solution for linear features, e.g. drainage ditches, where the free water area seldom takes up more than 30 % of the total area of the biotope, the rest being vegetation on the banks.

The digitalization could be done directly at the screen, or eventually supported by editing proposals given by routines such as "AREA", where it is obvious that no changes since the time of the airphotos has taken place. As discussed in part 2.b., a "true" delineation of many irregular formed patch small biotopes can be very difficult, but the development of GPS-instruments makes it possible in the future to make a very precise mapping in the field. Procedures for a similar semiautomatic registration of geo-codes for line-biotopes should be developed too, but will in practise not be so important, since most of the linear biotopes are straight lines being proper localized by only a few coordinates. Certain parts of the general land use might also be easier mapped by support of the air-photo-background, such as build-up-areas, gardens etc.

3. Having saved geo-information on a biotope the coding form concerning attributes (type, width, % wood-, herb-, reedmarsh- vegetation and clear water, average and maximum height and type of woody vegetation and signs on the status and function (e.g. cattle-watering, shelved trash and stones, wildlife foddering, electric power masts)) should turn up at the screen for direct registration ensuring that all necessary information will be saved, and that problems by interpretation will be solved in the field. A similar form concerning the land use units should turn up after a geo-coding of a land-use unit.

Biotopes and land units already registered should be highlighted on the relevant map layer to facilitate the control of eventually missing registrations.

In practise a part of the coding can be done from a car, but in some areas, much time will be spared if a laptop can be brought along in the field. Information from the interview could in principle be handled in the same direct way, but might for other reasons be omitted.

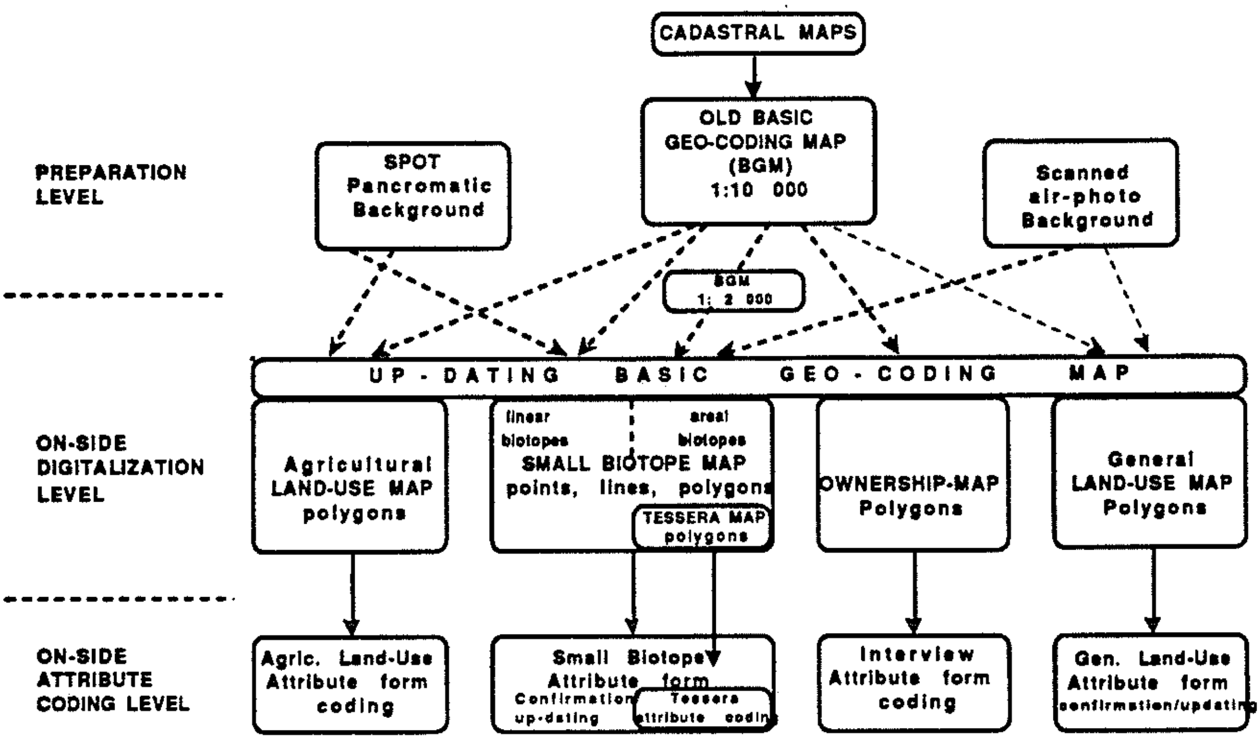


Figure 15: A framework for up-dating of SGEOS-aided interactive on-side registration of small biotopes and related data.

As can be seen from figure 15, the advantage of the described method will especially show up by updating of earlier investigations. It will be necessary to go through all objects (small biotopes, land-use-units and land ownership-units), to ensure the historical link giving possibilities for a detailed time-series analysis . But only a very little part of the geo-coding has to be changed, and for the attribute coding there will only be totally new data for agricultural land-use and probably also the interviews .

This method will not only be very timesaving, but also improve the reliability, since many of the problems that else will show up in the coding process, will be present during the field work, where it is much easier to judge how to handle it.

5 Summary and conclusion

Within the framework of this project, an operational working GIS has been set up, and integrated with digital image analysis tools. The system has been based on two existing software packages - ERDAS (image analysis) and GRASS (GIS and database), both of which are available on a lots of different kinds hardware platforms. ERDAS is commercial available, whereas GRASS is public domain and can easily be installed on almost any UNIX based workstation. GRASS is free of charge to everybody, but despite of this a very mature product - in contrast to many other public domain products - , with on line support and updates are available via network, directly from the US. The hardware environment used for this project is build up around UNIX based SUN SPARC workstations in a local area computer network.

The whole system comprises tools for input of different kinds of data, as digital maps in both vector and raster format, or raster images as Landsat TM data. Data exchange with external databases includes import of digital maps as well as extracts in tabular form, and export can be done the same way. Furthermore, printed maps or airphotos can be read into the database by digitizing or scanning paper copies. Powerful tools exist for preprocessing of scanned maps and images, including classification, colour separation, line thinning and vectorizing. Last not least data can be validated and errors detected on digital maps and images prior to database storage.

Standard procedures established and tested ensure possibility for future updates of the database in an easy way. A variety of data processing tools exist for digital image processing and for integrated analysis of vector and raster maps. Within the related databases, maps, images and statistical data can be stored efficiently, and converted from one database format to another.

Printed output can be produced as maps and tables on hardcopy or screen display. Examples are given in chapter 3.4, where the following data were used. All these data have been imported into the database and if necessary, corrected geometrically by rectification and map projection conversion to UTM zone 32 standard.

base maps:
- soil classification (JB-maps)
- geology in 1 meters depth
- histosol areas
- digital elevation model
- drainage network

remote sensing data:
- Landsat TM image May 15th 1988 (Funen)
- Landsat TM image May 18th 1989 (Both areas)
- scanned IR colour airphotos, May 15th 1988 (Funen)
- scanned colour airphotos, May 5th 1990 (Gundsø)

derived maps:
- drainage basins and network
- morphographic features (terrain shape index plus slope)

The examples prove, that the GIS and data set established, will provide a helpful tool for landscape ecological studies and marginal lands survey. Relevant parameters which can be derived are type of land use / land cover, hydrologic conditions (histosol areas, drainage network, soil texture), terrain form (undulating areas and steep slopes) and soil erosion risks.

A dedicated tool has been developed to run together with the image analysis package, for semiautomatic delineation of small biotopes. By means of this programme, type and size of patch biotopes can be determined and mapped interactively on the computer screen, based on scanned airphotos. Different ways of contrast enhancement have been tried on the scanned airphotos, prior to biotope delineation. The resulting vector map, produced by the developed tool, is stored directly into the database for later retrieval.

This tool works very well for patch biotopes, on interaction with a trained user. A similar mapping of linear biotopes will have to be done by either interactive digitizing on the screen, or a dedicated tool will have to be developed for this.

Finally, considerations are made about application of remote sensing images (SGEOS data and/or scanned airphotos) in connection to future small biotopes and marginal land surveys. No doubt, integrated use of remote sensing data together with an updated map database will be very useful for repeated mapping and monitoring purposes.

Of special interest will be a tool for interactive field digitizing, installed on a laptop equipped with high resolution screen. Positional accuracy has to be guarantied and may require a GPS, either to find necessary ground control points or for reading all locations directly in field.

Furthermore supplementary procedures for quick and up to date updating of the database should be established, i.e. in fields where new national databases holding cadastral information and topographic maps are under development.

References:

Agger, P. and J. Brandt (1988): Dynamics of small biotopes in Danish agricultural landscapes. Landscape Ecology Vol. 1 n° 4, p. 227-240.

Agger, P. and J. Brandt (1984): Registration methods for studying development of small scale biotope structures in rural Denmark.. Vol II pp. 71-72 In: (ed): J. Brandt and P. Agger: Proceedings of the first international seminar on methodology in landscape ecological research and planning,Vol I-V Roskilde University Centre. GEO-RUC.

Agger, P., S. Andersen, J. Brandt, T.S. Nielsen and A. Tvevad. (1987): Morænelandets marginaljorder - småbiotoper, flora og fauna, bynære marginaljorder og friluftsliv (The marginal soils of the morainic landscape)'. Miljøministeriets projektundersøgelser 1986. Samlerapport nr. VIII a. Skov- og Naturstyrelsen 1987.

Agger, P. and J. Brandt (1987): Småbiotoper og marginaljorder (Small biotopes and marginal soils). Miljøministeriets projektundersøgelser 1986. Teknikerrapport no. 35 . Skov- og Naturstyrelsen 1987.

Agger, P. (1991). Ecological consequences of current land-use changes in Denmark and some perspectives for planning and management. In J. Brandt (Ed.), European IALE-seminar on practical landscape ecology, IV (pp. 93-105). Roskilde: GeoRuc.

ASPRS (ed.) (1983): 'Manual of Remote Sensing'; American Society of Photogrammetric engineering and Remote Sensing.

Baudry, J. (1984): 'Effects of Landscape Structure and Biological Communities: The case of Hedgerow Network Landscapes'. In: Brandt & Agger (ed.) 'Proceedings of the first international seminar of IALE on methodology in landscape ecological research and planning, Roskilde University Centre, vol.I, pp 55-65.

Berry, Joseph K.: 'Fundamental operations in computer-assisted map analysis'. Int.J. Geographical Information Systems, 1987, Vol.1, No.2, 119-36.

Bramsnæs, A. and J. Brandt (1988): Efterlysning: Sammenhængende lokal landskabsforvaltning (Wanted: Integrated local landscape management). Byplan no. 3 1988, p. 94-98.

Brandt J. (1986): Small-biotope structures as a synthesizing feature in agricultural landscapes. In: Landscape synthesis - foundation, classification and management. Part. 1. Geoecological foundations, p. 52-61, Ed. by H. Richter and G. Schönfelder, Martin-Luther-Universität Halle-Wittenberg, Wissenschaftliche Beiträge 1986/16, Halle(saale), GDR.

Brandt J. and P. Agger (1988): The influence of EEC-agricultural policy on the conditions for development of biotope structures in rural landscapes: some Danish experiences. K.F. Schreiber (Hrsg.): Connectivity in landscape Ecology. Proceedings of the 2nd International Seminar of IALE. Münster 1987. Münstersche Geographische Arbeiten, 29, p. 218-221.

Brandt, J.(1988): Bounding territories for integrated local landscape management. In: Spatial and functional relationships in landscape ecology. Vol 3, p. 86-88. Proceedings of the VIIIth Int. symposium on problems of landscape ecological research, October 1988. Zemplínska sírava, CSSR.

Burel, F. (1992): 'Effect of Landscape Structure and Dynamics on Species Diversity in Hedgerow Networks'. Landscape Ecology, vol. 6/3 pp 161-174.

Burrogh, Peter A.: 'Principles of Geographical Information Systems for Land Ressources Assessment'. 193s, Oxford 1986.

Catlow, D.R., m.fl.: 'The integrated use of digital cartographic data and remotely sensed imagery'. Proc. EARSeL/ESA Symposium on Integrative Approaches in Remote Sensing, s.41-46. ESA 1984.

Christiansen, O. and Nielsen P. (1991): 'Småbiotop-kortlægning ved anvendelse af digitale luftfotos' ('Mapping of small biotopes by using digital airphotos'), M.Sc thesis, Roskilde 1991.

Cracknell, A.P.: 'Editorial - geographical information systems'. Int.J.Rem.Sens, 1986, no.6, s.721-2.

Crist, E.P.: Proc. Int. Symp. Machine Process. Remotely Sensed Data, pp. 357-363, 1983.

Dangermond J. (1990): 'A classification of software components commonly used in geographic information systems'; in: Peuquet, D.J. & Marble, D.F. (ed.): 'Introductory readings in Geographic Information Systems', Taylor & Francis, London.

Davis, John C.: 'Statistics and Data Analysis in Geology'. New York 1973.

Folving, Sten: 'Remote Sensing Techniques in landscape ecology'. IALE - theme 5. RUC 1984.

Forman, R. &. T., & Godron, M. (1986). Landscape Ecology. New York: John Wiley & Sons.

Goosens, R. et.al (1991): 'Satellite Interpretation (SPOT) for Survey of the Ecological Infrastructure in a Small Scaled Landscape'. Landscape Ecology vol. 5/3 pp 175-182.

Harries R.: Satellite Remote Sensing - An Introduction. London 1987.

Henein, K., & Merriam, G. (1990). 'The elements of connectivity where corridor quality is variable.' , 4(2/3), 157-171.

Ihse, H. (1984): 'Försvinnande biotoper i jordbrukslandscapet - Jämförande studier i flygbilder från 1940-talet till nutid i Ystadsområdet' (Disappearing biotopes in agricultural landscapes - Comparative studies from airphotos of 1940'ies and present in the Ystad area). Symposiet i Kulturlandskapet, dess framväkst och förandring (G. Regnell ed.). Lunds Universitet p.101-108.

Jackson, M.J., m.fl.: 'The development of integrated geo-information systems'. Int.J. Rem. sens, 1986, vol.7. no.6.,s.723-55.

Jensen, J. E.(1990): 'Nanochorer i Gundsφ kommune.' M.Sc.-Thesis Working Papers. no. 90. Inst. of Geography, Socio-economic analysis and Computer Science.Roskilde Univerisy 1990. (In print)

Johannsen, Chris J, m.fl: 'Remote sensing for resource management.' Soil Conservation Society of America 1982.

Landbrugsministeriet: 'Den Danske Jordklassificering' (The Danish Soil Classification), 1976.

Luz, F. (1991). 'The acceptance of de-intensification and habitat network schemes in agricultural landscapes in Germany'. In: World Congress of Landscape Ecology, Ottawa.

Madsen H. Breuning: 'Himmerlands jordbundsforhold'. Folia Geographica Danica. TOM XVI, 1983.

Madsen H.B.: The Construction of Root Zone Capacity Maps Based on Computerized Soil Maps and Pedological Data. Pedologie, XXXVI-2, p.133-154, 1986.

Meeus, JHA. et.al (1988): 'Changing agricultural landscapes in Europe'. Rotterdam.

Mohr Chr.: Determination of organic soil matter by titration. Väg- och vattenbyggaren 7-8, pp.19-21, 1979.

Mulders, M.A.: 'Remote Sensing in Soil Science'. Elsevier, Wageningen, Netherlands 1987. pp.55-89.

Münier B. (1990): 'A Hybrid GIS for Landscape Analysis and Mapping', in: Proceedings of the Third Scandinavian Research Conference on GIS, Helsingøre 1990.

Münier, B. & Petersen, J. W.: 'Vegetationskortlægning ved hjælp af satellitbilleder (Mapping of vegetation on danish Wadden See -Islands by satellit images)'. Publications from Institut of Geography, ...; Research report no. 42, Roskilde University, 1986.

Münier B. (1991): 'Integrating Data Sources in a GIS for Landscape Analysis & Mapping', in: Proceedings of the European Seminar on Practical Landscape Ecology, Roskilde 1991.

Münier, B.: 'The use of GIS in landscape-ecological studies of small biotopes and marginal lands'. Workshop on integration of remote sensing and PC-based geographical information system in the management of european marginal land. JRC, Ispra. September 1989.

Münier, B.: 'Mapping of shallow water areas - integration of satellite images and scanned airphotos'. Proceedings of the 9th EARSeL-Symposium, Helsinki 1989.

Niblack, Wayne: 'An Introduction to Digital Image Processing'. Strandberg 1985.

PE&RS (Photogrammetric Engineering and Remote Sensing - tidsskrift af: American Society of Photogrammetry and Remote Sensing).

Peuquet, D.J. (1990): 'A conceptual framework and comparison of spatial data models'; in: Peuquet, D.J. & Marble, D.F. (ed.): 'Introductory readings in Geographic Information Systems', Taylor & Francis, London.

Rambouskava, H. (1988 & 1989): 'Comments on the Ecostabilizing Functions of Small Scale Landscape Structures'. Ecologica (CSSR) vol. 7 no.4 pp 397-412 & vol. 8 no.1 pp 35-48.

Ranzinger,H. & M.: 'A geo-information expert system for synergetic use of map and image data'. Proc. EARSeL/ESA Symposium on Integrative Approaches in Remote Sensing, s.263-8. ESA 1984.

Rasmussen, R.O.: 'Geographical informative Systems and Computergraphics as tools in the landscape analysis and planning'. IALE - theme 3. RUC 1984.

Reeve M.J. et.al.: The Effect of Density on Water Retention Properties of Field Soils. J. Soil Sc., Vol 24 No.3 pp.355-367, 1973.

Robinove, Charles j.: 'The Logic of Multispektral Classifikation and mapping of Land'. Rem Sens. of Environment 11/1981, pp 231-44.

Ruthsatz, B. & Haber, W. (1982): 'The significance of smallscale landscape elements in rural areas as refugees for endangered plant species'. Persp. Landsc. Ecol. of congress, Netherlands, pp 117-124.

Schmel, H.J. & Englmaier, A. (1982): 'Zur Bedeutung naturnaher Kleinstruckturen für die Labdwirtschaft im Rahmen der Flurbereiningung'. Zeitshrift f. Kulturtechnik und Flurbereinigung 23 pp 75-86.

Schowengerdt, Robert A.: 'Techniques for Image Processing and Classification i Remote Sensing.' 1983.

Slater P.J. et.al.: The Influence of Texture on the Moisture Characteristics of Soils. J.Soil Sc., Vol 16 No.1 pp.1-15, 1965.

Smith, Terence R.: '... Implementation and construction of large scale geo-information systems'. Int.J. Geographical Information Systems, 1987, Vol.1, No.1, 13-31.

Tvevad, A. (1988). 'Vejledning i metoder til overvågning af småbiotoper i agerlandet'. No. Skov- og Naturstyrelsen.

Appendix:

Appendix A. Public access to GIS and database implemented under this project:

The system implemented under this project - both GIS, in house software and databases - can be made accessible to all participants of the collaborative programme with few acceptance.

Regarding the software, the GIS and all self developed programmes can be made available for copying from Roskilde University. Only the ERDAS image analysis system used for some purposes is a commercial product, and has to be purchased from ERDAS INC./USA.

Most of the basic data inside the database have been purchased within this project, and so they can be made available to all participants. Except for this is some data from existing Danish databases, but in many cases it should be possible to make those available by contacting the institutions holding the copyright.

Appendix B. Overview on data handling capabilities of RUGIS:

- input of
  - digital data:
    - satellite images
    - other raster data (digital elevation model, maps etc.)
    - vector maps (soil types, topographical maps (T0),....)
  - printed maps:
    - digitizing of existing printed maps
    - scanning of airphotos
  - other data in tabular form:
    - field work data
- storage of images, maps and data including:
  - geo references
  - attributes
  - topology
- processing:
  - digital image analysis (radiometric and geometric correction, image enhancement and classification)
  - geometric correction and rectification of maps (vector and raster) using n-degrees polynomial.
  - transformation between different coordinate systems, map projections and geoids applying map projection conversion package originally developed by US Geological Surveys.
  - boolean and algebraic operations on maps (raster & vector)
  - spatial texture and filtering / neighbourhood analysis.
  - modelling facilities on raster and vector maps.
  - interpolation and analysis of digital elevation models
  - analysis of terrain formes
  - statistical analysis on images and maps (raster & vector)
  - statistical analysis and modelling on tabular data.

- integration and conversion between raster and vector maps
- output of raster images and maps, vector maps and tabular or graphics output from statistics.

System development facilities:
- tools and documentation, for alteration and in house development of existing software systems.

Demands satisfied by RUGIS:
A brief list of the main topics:
+ operational working system with user documentation, on line help and good tools for users own application development
+ good raster and vector handling capabilities
+ fully topological vector data structure
+ integration of digital image analysis and hybrid GIS and statistics
- all conversion can be done, but sometimes it still works slowly and involve several steps.
+ relational database RIM included into GRASS public domain software
- missing SQL interface to other relational databases
+ data input/output facilities, including external database formats
- command driven, non graphics user interface without menus
+ high quality graphics output to screen and hardcopy devices
+ GRASS is a 'modern' GIS, designed and released in the middle of the 1980'ties to run on UNIX-based workstations
+ GRASS is public domain, including source code, and full service can be purchased by contract from different sites
+ GRASS has been - and is still - ported to almost all widespread types of UNIX workstations and to PC's
+ number of installations is estimated to several thousand, primarily in governmental agencies in the US, and at universities worldwide

Appendix C. Structure of the programme AREA:

On the next two pages is given an overview of the structure of the programme AREA, developed for semiautomated delineation of patch biotopes under this project. A detailed description, discussion and the listing of source code can be found in a specific report (Christiansen and Nielsen 1991).

Appendix D. GRASS 4.0 programs abstract:

The GRASS programs abstract printed on the subsequent pages has been taken from the set of GRASS tutorials, acquired via datanet (GRASS version 4.0 from summer 1991, including minor updates).

GRASS 4.0 PROGRAMS

ABSTRACT

This document lists the currently running programs associated with version 4.0 of the Geographic Resources Analysis Support System (GRASS), developed at the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (USA-CERL) in Champaign, IL.

1. GRASS

GRASS is a public domain image processing and geographic information system (GIS), written in the C programming language and running under the UNIX operating system. It was originally designed and developed by researchers in USACERL's Environmental Division to assist land managers at military installations. GRASS is now used by a wide variety of public and private agencies, including the Soil Conservation Service, National Park Service, U.S. Geological Survey, and many others. Some GRASS programs are contributed by these agencies and others. The system continues to be developed at USACERL.

GRASS version 4.0 includes roughly 270 commands, which adhere to the following naming conventions:

Prefix:
- d. - Display commands
- g. - General file management commands
- i. - Imagery commands
- m. - Data Import/Processing commands
- p. - Paint/Print commands
- r. - Raster data commands
- s. - Sites data commands
- v. - Vector data commands

Suffix:
- .sh - Shell scripts (macros)

This naming scheme indicates the data type (raster, vector, sites) on which a command operates, or the general functional area (display, imagery, data import/processing, general purpose) in which a command falls, or whether a command is a UNIX shell script macro.

In this paper, and in the GRASS on-line help system (accessed by typing **g.help** while running GRASS), commands are listed under their respective functional areas. The functional areas described here are as follows:

1 - General File Management
2 - "Window" Management
3 - Extracting Data from Magnetic Tape
4 - Data Conversion: Importing and Exporting Data
5 - Interfaces between GRASS and other Software
6 - Digitizing and Map Development
7 - Image Processing
8 - Analyzing Data in GRASS
9 - Map Display
10 - Printing Maps
11 - Report Generation
12 - Macro Development

2. General File Management Commands

The following GRASS commands perform general management functions. They are designed to assist in the management of files and data and to provide access to various GRASS help features.

d.ask -	Prompts the user to select a GRASS data base file from among files displayed in a menu on the graphics monitor.
exit -	Exits the user from the current GRASS session.
g.access -	Controls user access to the current GRASS mapset.
g.ask -	Prompts the user for the names of GRASS data base files.
g.copy -	Copies available data files in the user's current mapset search path and location to the appropriate element directories under the user's current mapset.
g.filename -	Prints GRASS data base file names.
g.findfile -	Searches for GRASS data base files and sets variables for the shell.
g.gisenv -	Outputs the user's current GRASS variable settings.
g.help -	GRASS help utility.
g.list -	Lists available GRASS data base files of the specified data type to standard output.
g.manual -	Accesses GRASS reference manual entries.
g.mapsets -	Modifies the user's current mapset search path, affecting the user's access to data existing under the other GRASS mapsets in the current location.
g.region -	Program to manage the boundary definitions for the geographic region.
g.remove -	Removes data base element files from the user's current mapset.
g.rename -	To rename data base element files in the user's current mapset.
g.version -	Outputs the GRASS version number and date.

3. "Window" Management

These commands deal with the management of the two types of 'windows' available in GRASS: graphics display frames and geographic regions.

3.1. Management of Graphics Display Frames

After the user has started and selected a graphics monitor for output (using the *d.mon* command), the user can subdivide the monitor into different "frames", and display different GRASS outputs in each frame. For example, the GRASS macro *3d.view.sh* divides the monitor into nine frames to demonstrate

the 3-d viewing function of GRASS.
The following commands are used to manage the frames in which graphics are displayed on the user's graphics display device (monitor). These commands affect only the display of graphics, and do not alter the user's data. In past GRASS releases, "graphics frames" were referred to as "graphics windows"; the latter term is now obsolete.

d.erase - Erases the active display frame on the graphics monitor.

d.frame - Manages display frames on the graphics monitor.

3.2. Defining/Management of the Geographic Region

The commands listed below can be used to modify the settings of the user's geographic region. This settings of this region define the geographic boundaries, map projection, coordinate system, and resolution of a data set. GRASS commands commonly ignore data falling outside of this region. For example, when raster analysis programs are run on map layers, only those map areas that fall inside the user's current geographic region will be analyzed and included in the resultant map layer. In previous GRASS releases, the geographic region definition was referred to as the "geographic window"; the latter term is now obsolete.

d.zoom - Allows the user to change the current geographic region settings interactively, with a mouse.

g.region - Program to manage the boundary definitions for the geographic region.

r.mask - Establishes and removes the current working mask.

4. Extracting Data from Magnetic Tapes

Several GRASS commands exist to examine and extract specific types of data from magnetic tape. Some of these programs are listed below.

4.1. Examining, Extracting and Rotating Elevation Tape Data

The U.S. Geological Survey (USGS) and the Defense Mapping Agency (DMA) distribute digital elevation data at several resolutions and in different tape formats. These data are referred to as digital elevation models (DEMs) and digital terrain elevation data (DTED). The GRASS programs listed below extract this data from 1/2" magnetic tape, list tape contents, rotate the data, and "flip" the data. USACERL distributes brief papers that distinguish elevation data types and detail the sequence of GRASS commands relevant to each.

m.examine.tape - Provides a description of the files on a 1/2-inch magnetic tape.

m.dem.examine - Provides a terse description of USGS Digital Elevation Model (DEM) data files stored on 1/2-inch magnetic tape.

m.dem.extract - Extracts USGS Digital Elevation Model (DEM) data from 1/2-inch magnetic tape.

m.dmaUSGSread - Extracts digital terrain elevation data (DTED) produced by the Defense Mapping Agency (DMA) but supplied by the USGS (in a different tape format) on 1/2-inch magnetic tape.

m.dted.examine - Provides a terse description of level 1 and 2 digital terrain elevation data (DTED) files produced and distributed by the Defense Mapping Agency (DMA) on 1/2-inch magnetic tapes.

m.dted.extract - Extracts digital terrain elevation data (DTED - levels 1 and 2) produced and supplied by the Defense Mapping Agency (DMA) on 1/2-inch magnetic tapes.

m.flip - Flips the orientation of map data.

m.rot90 - Rotates elevation data extracted by either *m.dted.extract* or *m.dmaUSGSread.*

4.2. Extracting Imagery Data

Several GRASS commands are also available to extract specific forms of satellite imagery data from magnetic tape. The below commands extract LANDSAT multi-spectral scanner (MSS), Thematic Mapper (TM), and other (e.g., SPOT) satellite data, as well as header information, from tape. The *GRASS Imagery Tutorial* distributed by USACERL discusses imagery data and details the logical sequence of GRASS commands relevant to these different data forms.

i.tape.mss - An imagery function that extracts Multispectral Scanner (MSS) imagery data from half-inch tape.

i.tape.mss.h - An imagery function that extracts header information from Landsat Multispectral Scanner (MSS) imagery data stored on half-inch tape.

i.tape.other - An imagery function that extracts scanned aerial imagery (NHAP, etc.) and SPOT imagery from half-inch magnetic tape.

i.tape.tm - An imagery function that extracts LANDSAT Thematic Mapper (TM) imagery from half-inch magnetic tape.

5. Data Conversion: Importing and Exporting Data

The commands listed below are useful to those importing and exporting data to and from GRASS. They perform ASCII/binary data conversions, raster, vector, and sites data format conversions, GRASS/other data format conversions, and map coordinate system and map projection conversions.

5.1. Moving Data to Another Computer - ASCII/Binary Conversions

These commands assist in ASCII/binary conversion of data. Specifically, commands with the .ascii extension bring data in from ASCII (to binary) and out to ASCII (from binary). Those with a .dlg extension bring data in from DLG-3 Optional format (to GRASS vector format) and out to DLG-3 Optional format (from GRASS vector format).

r.in.ascii - Converts an ASCII text file into a raster map layer.

r.out.ascii - Converts a raster map layer into an ASCII text file.

s.in.ascii - Converts a GRASS site_lists file in ASCII format to binary format.

s.out.ascii - Converts a GRASS site_lists file in binary format to ASCII format.

v.in.ascii - Converts ASCII vector map layers into binary vector map layers.

v.out.ascii - Converts binary vector map layers into ASCII vector map layers.

v.in.dlg - Converts binary DLG (BDLG) file to binary vector (dig) file.

v.out.dlg - Converts binary GRASS vector data to binary DLG-3 Optional format.

v.import - Converts ASCII Digital Line Graph (DLG) files, binary DLG files, and ASCII vector files into binary vector files and creates the needed vector support files.

5.2. Raster/Vector/Sites Conversions

These commands convert data among GRASS raster, vector and sites formats.

r.line - Creates a new GRASS vector (dig) file by extracting linear features from a thinned raster file.

r.poly - Extracts area edges from a raster map layer and converts data to vector format.

r.thin - Thins non-zero cells that denote linear features in a raster file.

r.in.sunrast - Converts a SUN raster file to a GRASS raster file.

r.in.ll - Creates a raster file from data in latitude, longitude coordinates.

s.in.ascii - Converts a GRASS site_lists file in ASCII format to binary format.

s.out.ascii - Converts a GRASS site_lists file in binary format to ASCII format.

v.to.rast - Converts a map layer in (binary) GRASS vector format to GRASS raster format.

v.to.sites - Converts a GRASS vector file to a GRASS site_lists file.

5.3. GRASS to/from Other File Format Conversions

These commands convert GRASS files to/from such other file formats as ARC-INFO, DLG-3 Optional, DXF, and MOSS.

v.in.arc - Converts data in ARC/INFO format to GRASS's vector format, and stores output in the user's current GRASS mapset.

v.out.arc - Converts GRASS vector files to ARC/INFO's "Generate" file format.

v.in.dlg - Converts binary DLG (BDLG) file to binary vector (dig) file.

v.out.dlg - Converts binary GRASS vector data to binary DLG-3 Optional format.

v.in.dxf - DXF format to GRASS vector format conversion program.

v.out.dxf - GRASS vector format to DXF format conversion program.

v.in.tiger - Imports and converts line data in Census Bureau TIGER format to GRASS's vector format, and stores output in the user's current GRASS mapset.

v.out.moss - Converts GRASS site, line, or area data into MOSS import format.

r.in.sunrast - Converts a SUN raster file to a GRASS raster file.

m.lulc.USGS - Creates raster map layers from a Composite Theme Grid (CTG) file created by *m.lulc.read*. *m.lulc.read* extracts the CTG data from an ASCII landuse/landcover (lulc) CTG format file supplied by the USGS.

Gen.Maps - Generates various vector map layers from a RIM/TIGER database.

Gen.tractmap - Generates two vector map layers from a RIM/TIGER database.

5.4. Coordinate Conversions and Map Projections

The user can also perform map coordinate conversions and map projection transformations, using the GRASS commands listed below.

m.datum.shift - Datum shift program.

m.gc2ll - Converts geocentric to geographic coordinates.

m.ll2gc - Converts geographic coordinates to geocentric coordinates.

m.ll2u - Converts geographic (latitude/longitude) coordinates to Universal Transverse Mercator (UTM) coordinates.

m.u2ll - Converts Universal Transverse Mercator (UTM) coordinates to geographic (latitude/longitude) coordinates.

m.lulc.read - Extracts Landuse/Landcover data in the ASCII Composite Theme Grid (CTG) data format distributed by the USGS into a working file for *m.lulc.USGS*.

m.lulc.USGS - Creates raster map layers from a Composite Theme Grid (CTG) file created by *m.lulc.read*. *m.lulc.read* extracts the CTG data from an ASCII landuse/landcover (lulc) CTG format file supplied by the USGS.

m.region.ll - Converts Universal Transverse Mercator (UTM) coordinates falling within the current geographic region from UTM coordinates to geographic (latitude/longitude) coordinates.

m.tiger.region - Program to extract the boundaries of a geographic region sufficient to encompass all data in a user-specified TIGER file.

r.mapcalc - Raster map layer data calculator.

r.in.ll - Creates a raster file from data in latitude, longitude coordinates.

v.transform - Transforms an ASCII vector map layer from one coordinate system into another coordinate system.

Satellite imagery data are generally made available in an x,y coordinate system. In order to analyze imagery data in combination with other GRASS data layers, it is necessary that all these data be rectified to the same map coordinate system and projection. Several GRASS programs are used to rectify imagery data.

i.points - An imagery function that enables the user to mark coordinate system points on an image to be rectified and then input the coordinates of each point for creation of a coordinate transformation matrix. The transformation matrix is needed as input for the GRASS program *i.rectify*.

i.rectify - An imagery function that rectifies an image by computing a coordinate transformation for each cell (pixel) in the image using the transformation coefficient matrix created by the GRASS program *i.points*.

i.rectify.blk - An imagery function that ortho-rectifies an imagery group file.

6. Interfaces between GRASS and other Software

One function usefully performed by GRASS is to output data in a form suitable for input to other existing computer models. GRASS programs allow GRASS data to be interfaced with those of the BNOISE (blast noise simulation), X-Windows (X-Windows user interface), MAPGEN (map generation functions for plotter output), PPM (portable pix-map utilities), ARMSED (watershed and sedimentation modeling), ELAS (image processing), UW-RIM (University of Washington's version of the RIM relational data base management system), the "S" statistical package, and ISM (interactive surface modeling) programs. The user can, of course, use GRASS programs to put data into a form suitable for import and export to/from programs other than these.

7. Digitizing and Map Development

To be used by GRASS programs, data must be digitally stored in a GRASS data base. Data can be entered into a GRASS data base in one of several ways. (1) Hardcopy data (like paper maps) may be either digitized or scanned into GRASS's vector file format; (2) data already available in another digital format (like ARC-INFO data) may be converted into GRASS's digital data file format, and stored in a GRASS data base; (3) GRASS analysis programs can be used to create new GRASS data from data already stored in GRASS digital data file format. The GRASS programs listed below are designed for the input, manipulation, and adjustment of data from sources outside of GRASS.

7.1. Digitizing Maps

These commands allow for the addition of paper (and other hardcopy geographic information) into GRASS data bases, and for the manipulation of vector data in GRASS.

r.patch - Creates a composite raster map layer by using known category values from one (or more) map layer(s) to fill in areas of "no data" in another map layer.

r.random - Creates a raster map layer and sites list containing randomly located sites.

s.menu - Accesses and manipulates GRASS sites data.

v.digit - A menu-driven, highly interactive map development program used for vector digitizing, editing, labeling and converting vector data to raster format.

v.mkgrid - Creates a (binary) GRASS vector map of a user-defined grid.

v.mkquads - Creates a GRASS vector map layer and/or sites list and/or geographic region definition file for a USGS 7.5-minute quadrangle.

v.patch - Creates a new binary vector map layer by combining other binary vector map layers.

v.support - Creates GRASS support files for (binary) GRASS vector data.

v.to.rast - Converts a map layer in (binary) GRASS vector format to GRASS raster format.

v.to.sites - Converts a GRASS vector file to a GRASS site_lists file.

7.2. Editing and Patching Map Data

Frequently, (due to the size of digitizing tablets) users digitize data in relatively small chunks which must be "patched" together before data are analyzed. The GRASS commands listed below are used to edit and patch digital data.

r.mapcalc - Raster map layer data calculator.

r.patch - Creates a composite raster map layer by using known category values from one (or more) map layer(s) to fill in areas of "no data" in another map layer.

v.patch - Creates a new binary vector map layer by combining other binary vector map layers.

v.prune - Prunes points from binary GRASS vector data files.

v.spag - Processes a Spaghetti-digitized vector file.

7.3. Creating Support Files for GRASS Maps

A variety of supporting information is needed for each GRASS "map layer". For data stored in GRASS vector format, information on the location of vectors, the file topology, vector category values, and category labels are stored in separate files. For data stored in GRASS raster format, additional files are also stored to hold information on category colors, the map's development history, etc. The below programs help the user build necessary GRASS support files for raster and vector data.

r.support - Allows the user to create and/or modify raster map layer support files.

v.support - Creates GRASS support files for (binary) GRASS vector data.

7.4. Importing and Exporting Data to Other Data Formats

Often, data which one wishes to use in a GRASS data base are already available in digital data formats other than GRASS. Similarly, users often wish to export data from GRASS into other software systems' data formats. A number of GRASS programs are available to import and export data to and from GRASS. These are listed below.

r.in.ascii - Converts an ASCII text file into a raster map layer.

r.in.ll - Creates a raster file from data in latitude, longitude coordinates.

r.out.ascii - Converts a raster map layer into an ASCII text file.

v.import - Converts ASCII Digital Line Graph (DLG) files, binary DLG files, and ASCII vector files into binary vector files and creates the needed vector support files.

v.in.dxf - DXF format to GRASS vector format conversion program.

v.out.dxf - GRASS vector format to DXF format conversion program.

v.support - Creates GRASS support files for (binary) GRASS vector data.

8. Image Processing

Remotely-sensed images, such as satellite data and aerial photographs, are widely available in a digital format. The data in these images can be interpreted using image processing techniques that classify image elements based on the spectral reflectance values of individual image pixels or on user-identified pixel groupings. GRASS integrates GIS with image processing capabilities. This allows image data to augment a GRASS data base, and allows image classifications to be guided by known elements in other maps in the GIS data base. Processing of remotely-sensed imagery typically involves:

(1) extracting data from their magnetic storage media, (2) entering extracted data into a GRASS data base, (3) classifying pixels and elements in the image, (4) rectifying the image to a map coordinate system and projection, and (5) correcting and enhancing the image.

GRASS commands commonly used to perform image processing are listed below. Because imagery are stored as raster data, the GRASS raster analysis functions can be used to analyze imagery. The paper *r.mapcalc: An Algebra for GIS and Image Processing*, describes ways in which *r.mapcalc* can be used as an image processing tool.

8.1. Tape Extraction

Once imagery data are obtained from agencies, they must be extracted from the magnetic tapes on which they are stored. GRASS commands exist to extract LANDSAT Thematic Mapper (TM), Multi-Spectral Scanner (MSS), and such other satellite imagery as SPOT data from half-inch magnetic tape. Procedures for extracting this data from tape and importing it into a GRASS data base are described in the *GRASS Imagery Tutorial.*

i.tape.mss - An imagery function that extracts Multispectral Scanner (MSS) imagery data from half-inch tape.

i.tape.mss.h - An imagery function that extracts header information from Landsat Multispectral Scanner (MSS) imagery data stored on half-inch tape.

i.tape.other - An imagery function that extracts scanned aerial imagery (NHAP, etc.) and SPOT imagery from half-inch magnetic tape.

i.tape.tm - An imagery function that extracts LANDSAT Thematic Mapper (TM) imagery from half-inch magnetic tape.

8.2. File Management

Users can "group" imagery files for analysis purposes, and "target" imagery files to the files in another GRASS location. These are basic commands for the management of imagery files.

i.group - An imagery function that creates and edits groups and subgroups of (raster) imagery files.

i.target - An imagery function that establishes a GRASS target LOCATION for an imagery group.

8.3. Image Classification

Image classification is the process of categorizing the data in a raster image based on the spectral reflectance values of each map pixel (cell). Classification can be done using unsupervised or supervised methods. GRASS contains functions to conduct both kinds of classifications. In a supervised classification, the user can define the categories into which pixels are to be placed; in an unsupervised classification, the computer attempts to categorize pixels in a user-defined number of attempts based on statistical regularities in the data.

i.cca - Canonical components analysis (cca) program for image processing.

i.class - An imagery function that generates spectral signatures for an image by allowing the user to outline regions of interest. The resulting signature file can be used as input for *i.maxlik* or as a seed signature file for *i.cluster*.

i.cluster - An imagery function that generates spectral signatures for land cover types in an image using a clustering algorithm. The resulting signature file is used as input for *i.maxlik*.

i.maxlik - An imagery function that classifies the cell spectral reflectances in imagery data based on the spectral signature information generated in *i.cluster*.

i.pca - Principal components analysis (pca) program for image processing.

i.zc - Zero-crossing "edge detection" raster function for image processing.

r.mapcalc - Raster map layer data calculator.

8.4. Geometric Rectification

Imagery data are generally made available in an x,y coordinate system. In order to analyze imagery data in combination with other GRASS data layers, it is necessary that all these data be rectified to the same coordinate system and map projection. Several GRASS programs are used to rectify imagery data.

i.points -	An imagery function that enables the user to mark coordinate system points on an image to be rectified and then input the coordinates of each point for creation of a coordinate transformation matrix. The transformation matrix is needed as input for the GRASS program *i.rectify.*
i.rectify -	An imagery function that rectifies an image by computing a coordinate transformation for each cell (pixel) in the image using the transformation coefficient matrix created by the GRASS program *i.points.*
i.rectify.blk -	An imagery function that ortho-rectifies an imagery group file.

8.5. Image Correction

Commonly, when analyzing multiple images, it is necessary to correct image distortions attributable to such sources as the earth's radiation. Such distortions can result in different spectral reflectance values being collected for the same image pixel, based on the time of day, month, year, etc., at which the image was photographed. GRASS programs exist which help the user to identify and eliminate such distortions from images, allowing valid comparisons to made among images. See the paper *r.mapcalc: An Algebra for GIS and Image Processing* for an example of how radiometric corrections can be made to an image.

i.fft -	Fast Fourier Transform (FFT) for image processing.
i.ifft -	Inverse Fast Fourier Transform (ifft) for image processing.
r.mapcalc -	Raster map layer data calculator.

8.6. Image Enhancement

GRASS programs can be used to enhance or subdue certain data values, in order to make more evident certain features or qualities of digital imagery.

i.colors -	An imagery function that creates colors for imagery groups.
i.composite -	An imagery function that creates a color composite image from three band files specified by the user.
i.grey.scale -	An imagery function that assigns a histogram contrast stretch grey scale color table to a raster map layer.
i.his.rgb -	Hue-intensity-saturation (his) to red-green-blue (rgb) raster map color transformation function.
i.rgb.his -	Red-green-blue (rgb) to hue-intensity-saturation (his) function for image processing.
r.mapcalc -	Raster map layer data calculator.

8.7. Building Custom Filters

The user may wish to model interactions across a landscape, or to remove systematic distortions occurring across a map or image. Both applications can be approached by filtering data. The user can build custom filters to make the value of one pixel a (user-defined) function of the values in the surrounding cells. The paper *r.mapcalc: An Algebra for GIS and Image Processing* provides examples of how some spatial filters commonly used in image processing can be built using *r.mapcalc.* See also the section below on "Analyzing Data in GRASS: Neighborhood Analysis/Filters."

i.zc -	Zero-crossing "edge detection" raster function for image processing.
r.mapcalc -	Raster map layer data calculator.

r.mfilter -	Raster file matrix filter.
r.neighbors -	Makes each cell category value a function of the category values assigned to the cells around it, and stores new cell values in an output raster map layer.

9. Analyzing Data in GRASS

GRASS was designed as an image processing and map analysis system. Most GRASS analysis programs operate on raster data; *s.db.rim* operates on site data. GRASS programs exist that allow the user to convert GRASS data between raster, vector, and site formats. GRASS data analysis functions can be employed for such tasks as: (1) general data manipulation, (2) site data analysis, (3) two- and three-dimensional manipulations, (4) single cell map reporting functions, (5) multi-cell coincidence tabulations and comparisons, (6) neighborhood analysis and filtering, (7) regional analysis and filtering, (8) proximity analysis, (9) Boolean overly functions, and (10) terrain analysis functions.

9.1. General Data Manipulation and Analysis Tools

The programs listed below are used for general data manipulation and analysis. Several of these programs are also cross-listed under other categories.

r.binfer -	Bayesian expert system development function.
r.colors -	Creates/Modifies the color table associated with a raster map layer.
r.combine -	Allows category values from several raster map layers to be combined.
r.grow -	Generates an output raster map layer with contiguous areas grown by one cell (pixel).
r.infer -	Outputs a raster map layer whose category values represent the application of user-specified criteria (rules statements) to other raster map layers' category values.
r.mapcalc -	Raster map layer data calculator.
r.mapmask -	Establishes and removes the current working map mask.
r.mask -	Establishes and removes the current working mask.
r.pat.place -	Allows a user to place a pattern of the user's choice at a particular location and in a desired direction.
r.reclass -	Creates a new map layer whose category values are based upon the user's reclassification of categories in an existing raster map layer.
r.resample -	GRASS raster map layer data resampling capability.
r.rescale -	Rescales the range of category values in a raster map layer.
r.weight -	Interactive raster map overlay function.
s.db.rim -	RIM data base management/query interface for GRASS.
v.db.rim -	RIM data base management/query interface for GRASS vector maps.

9.2. Site Data

Site data can be analyzed in GRASS either in their site format or after conversion to raster data format. The following GRASS programs are used to analyze site data.

s.db.rim -	RIM data base management/query interface for GRASS.
s.menu -	Accesses and manipulates GRASS sites data.
s.surf.idw -	Surface generation program, from sites data.

9.3. 2-D and 3-D Manipulations

GRASS programs can be used to perform two- and three-dimensional data manipulations. These functions are useful for modeling iterative interactions across a landscape.

r.basins.fill -	Generates a raster map layer showing watershed subbasins.
r.drain -	Traces a flow through an elevation model on a raster map layer.
r.surf.contour -	Surface generation program.
r.surf.idw -	Surface generation program, using raster data.
r.surf.idw2 -	Surface generation program, using raster data.
r.watershed -	Watershed basin analysis program.

9.4. Single Cell Map Reporting Functions

The functions listed below report information about a single cell, in one or more raster map layers.

d.what.rast -	Allows the user to interactively query the category contents of multiple raster map layers at user-specified locations within the current geographic region.
r.describe -	Prints terse list of category values found in a raster map layer.
r.info -	Outputs basic information about a user-specified raster map layer.
r.report -	Reports statistics for raster map layers.
r.stats -	Generates area statistics for raster map layers.
r.what -	Queries raster map layers on their category values and category labels.
r.volume -	Sums cell values within clumps and calculates volumes and centroids of patches or clumps.

9.5. Multi-Cell Coincidence Tabulations and Comparisons

The GRASS functions listed below report back information about multiple cells in one or more map layers, in a way useful for making correlations among data.

d.what.rast -	Allows the user to interactively query the category contents of multiple raster map layers at user-specified locations within the current geographic region.
r.coin -	Tabulates the mutual occurrence (coincidence) of categories for two raster map layers.
r.report -	Reports statistics for raster map layers.
r.stats -	Generates area statistics for raster map layers.
r.what -	Queries raster map layers on their category values and category labels.

9.6. Neighborhood Analysis/Filters

The user may wish to model interactions across a landscape, or to remove systematic distortions occurring across a map or image. The user may also wish to eliminate "noise" from map data in order to make the basic results more visually apparent. Such applications can be approached by filtering data. The user can build custom filters to make the value of one pixel a (user-defined) function of the values in the surrounding cells. The paper *r.mapcalc: An Algebra for GIS and Image Processing* provides examples of how some spatial filters commonly used in image processing can built using *r.mapcalc.* See also past issues of the newsletter *GRASSClippings* for other examples of custom filters for specific applications. See also the section above on "Image Processing: Building Custom Filters."

r.basins.fill -	Generates a raster map layer showing watershed subbasins.
r.buffer -	Creates a raster map layer showing buffer zones surrounding cells that contain non-zero category values.
r.cost -	Outputs a raster map layer showing the cumulative cost of moving between different geographic locations on an input raster map layer whose cell category values represent cost.

r.clump - Recategorizes data in a raster map layer by grouping cells that form physically discrete areas into unique categories.

r.drain - Traces a flow through an elevation model on a raster map layer.

r.grow - Generates an output raster map layer with contiguous areas grown by one cell (pixel).

r.mapcalc - Raster map layer data calculator.

r.neighbors - Makes each cell category value a function of the category values assigned to the cells around it, and stores new cell values in an output raster map layer.

r.slope.aspect - Generate raster map layers of slope and aspect from a raster map layer of true elevation values.

r.thin - Thins non-zero cells that denote linear features in a raster file.

r.watershed - Watershed basin analysis program.

9.7. Regional Analysis/Filters

GRASS can also be used to analyze and filter data "regions". Neighborhood filters modify each cell value as a function of the cell values found in its (square) neighborhood. Regional filters make each cell value a function of the values found within its (user-defined) region/clump of cells. A region can be defined as a contiguous group of cells having the same category value. Such filters are useful for imagery analysis and other applications.

i.zc - Zero-crossing "edge detection" raster function for image processing.

r.average - Finds the average of values in a values map within polygons of a user-specified base map.

r.clump - Recategorizes data in a raster map layer by grouping cells that form physically discrete areas into unique categories.

r.volume - Sums cell values within clumps and calculates volumes and centroids of patches or clumps.

9.8. Proximity Analysis

GRASS can be used to examine the proximity of certain map categories from others. Often, this is useful when determining which geographic areas warrant further analysis. For example, if investigating potential nesting sites of species X, the user might restrict his analysis to areas within a 300-meter radius of cells containing relevant species habitat.

r.buffer - Creates a raster map layer showing buffer zones surrounding cells that contain non-zero category values.

9.9. Boolean Overlay Functions

GRASS can perform basic Boolean overlay functions, involving data union ("or" operations), intersection ("and" operations), and exclusion ("not" operations). The GRASS commands listed below are used to do this.

r.combine - Allows category values from several raster map layers to be combined.

r.cross - Creates a cross product of the category values from multiple raster map layers.

r.infer - Outputs a raster map layer whose category values represent the application of user-specified criteria (rules statements) to other raster map layers' category values.

r.mapcalc - Raster map layer data calculator.

9.10. Terrain Analysis

Elevation data are crucial to any GIS. A number of GRASS commands were designed specifically to address terrain analysis issues related to water movement, development of ballistic trajectories, and computation of slope and aspect. Although the GRASS commands listed below were designed to analyze terrain data, they in fact can be used to analyze any data types. See also *d.3d*, *r.mapcalc*, *r.clump*, and the paper *r.mapcalc: An Algebra for GIS and Image Processing.*

r.cost - Outputs a raster map layer showing the cumulative cost of moving between different geographic locations on an input raster map layer whose cell category values represent cost.

r.drain - Traces a flow through an elevation model on a raster map layer.

r.los - Line-of-sight raster analysis program.

r.slope.aspect - Generate raster map layers of slope and aspect from a raster map layer of true elevation values.

r.traj - Ballistic trajectory model.

r.traj.data - Reviews the ammunition and weapon data base used by *r.traj*.

r.volume - Sums cell values within clumps and calculates volumes and centroids of patches or clumps.

r.watershed - Watershed basin analysis program.

10. Map Display

GRASS includes a full range of functions for display of GRASS outputs on the user's graphics device. These commands manage the graphics display device (monitor), manage the display frames to which output is sent, report on the contents of the images displayed to the monitor, and are used for map design, display, input and screen capture.

10.1. Management of Graphics Display Monitor

GRASS supports the use of multiple graphics display monitors during a GRASS session. The *d.mon* command is used to start, select, stop, and unlock graphics monitors for GRASS display output.

d.mon - To establish and control use of a graphics display monitor.

10.2. Management of Display Frames on the Graphics Display Monitor

After the user has started and selected a graphics monitor for output, the user can subdivide the monitor into different "frames", and display different GRASS outputs in each frame. For example, the GRASS program *i.points* divides the monitor into multiple frames to allow the user to target rectification points on an image to (user-known) points on another map layer. Similarly, the GRASS macro *3d.view.sh* divides the monitor into nine frames to demonstrate the 3-d viewing function of GRASS.

d.erase - Erases the active display frame on the graphics monitor.

d.frame - Manages display frames on the graphics monitor.

10.3. Map Display Reporting Functions

Several GRASS commands enable the user to query the contents of raster map layers displayed in the active frame on the user's graphics monitor.

d.measure - Measures the lengths and areas of features drawn by the user in the active display frame on the graphics monitor.

d.what.rast - Allows the user to interactively query the category contents of multiple raster map layers at user-specified locations within the current geographic region.

d.what.vect - Allows the user to interactively query the category contents of multiple (binary) vector map layers at user-selected locations within the current geographic region.

d.where - Identifies the geographic coordinates associated with point locations in the active frame on the graphics monitor.

10.4. Map Design, Display, Input and Capture

Numerous GRASS commands enable the user to develop, display, and capture raster, vector, site, textual, and symbol/icon data to the graphics display monitor. Similar functions are available for hard-copy map design and output (see "Printing Maps", below).

grass.logo.sh -	Displays a GRASS/Army Corps of Engineers logo in the active display frame on the graphics monitor.
show.color.sh -	Displays and names available primary colors used by GRASS programs, in frames on the graphics monitor.
show.fonts.sh -	Displays and names available font types in the active display frame on the graphics monitor.
slide.show.sh -	Displays a series of raster map layers existing in the user's current mapset search path on the graphics monitor.
3d.view.sh -	Displays nine three-dimensional views of the spearfish sample data set on the user's graphics monitor, demonstrating use of the program *d.3d.*
d.3d -	Three-dimensional raster map display program.
d.colormode -	Allows the user to establish whether a map will be displayed using its own color table or the fixed color table of the graphics monitor.
d.colors -	Allows the user to interactively change the color table of a raster map layer displayed on the graphics monitor.
d.colortable -	To display the color table associated with a raster map layer.
d.display -	Interactive program to display textual, symbolic, raster, vector, and site data in the active frame on the user's graphics monitor.
d.font -	Selects text fonts to be used for text display on the graphics monitor.
d.geodesic -	Displays a geodesic line, tracing the shortest distance between two geographic points along a great circle, in a longitude/latitude data set.
d.graph -	Program for generating and displaying simple graphics to the graphics display monitor.
d.grid -	Overlays a user-specified grid in the active display frame on the graphics monitor.
d.his -	Produces and displays a raster map layer combining hue, intensity, and saturation (his) values from user-specified input raster map layers.
d.histogram -	Plots a histogram in the form of a pie or bar chart for a user-specified raster file.
d.icons -	Displays points, as icons, at user-defined locations in the active display frame on the graphics monitor.
d.label -	Creates and places text labels in the active display frame on the graphics monitor.
d.labels -	To create/edit GRASS label files for display on the graphics monitor.
d.legend -	Displays a legend for a raster map layer in the active frame on the graphics monitor.
d.mapgraph -	Generates and displays simple graphics on raster map layers drawn in the active graphics monitor display frame.
d.menu -	Creates and displays a menu within the active frame on the graphics monitor.
d.paint.labels -	Displays text labels formatted for use with GRASS paint (*p.map, p.labels*) output to the active frame on the graphics monitor.
d.points -	Displays point graphics in the active frame on the graphics display monitor.
d.profile -	Displays profiles of a user-specified raster map layer in the active frame on the user's graphics monitor.
d.rgb -	Allows multiple maps to be overlaid in the active display frame on the graphics monitor.

d.rhumbline - Displays the rhumbline joining two user-specified points in the active frame on the user's graphics monitor.

d.scale - Displays a map scale and north arrow relevant to a the user's current geographic region setting in the active display frame on the graphics monitor.

d.sites - Displays site markers in the active display frame on the graphics monitor.

d.text - Draws text in the active display frame on the graphics monitor.

d.title - Outputs a title for a raster map layer in a form suitable for display by *d.text*.

d.vect - Displays GRASS vector data in the active frame on the graphics monitor.

d.vect.dlg - Displays a vector USGS digital line graph (DLG-3) file in the active frame on the graphics monitor.

11. Printing Maps

The map printing process parallels that for map display. Typically, however, printing of outputs is done only after all map analysis is complete. The user should design a map's contents, select a paint device (printer) to which output will be sent, and then print the map.

11.1. Designing Maps for Printed Output

A full range of map design functions, similar to those available for map display, are accessed through the GRASS commands listed below.

p.chart - Prints a color chart for the printer currently selected by the user.

p.colors - Allows the user to modify a color table for a raster map layer, assigning colors to the categories in the raster map layer based on printer color numbers (instead of red, green, blue percentages).

p.icons - Allows the user to create and maintain icons which are used by the *p.map* command to depict sites.

p.labels - Creates and modifies labels for hardcopy maps.

p.map - Command language interface to color hardcopy and graphics monitor output.

11.2. Choosing a Printer for Hardcopy Output

A user may have several printers (and display devices) connected to a GRASS system. Before printing a map, the user must first select which device will be used to print output produced by the GRASS paint/print commands. In GRASS, the *p.select* command is used to select a device for paint/print output. The *GRASS Hardware Configuration Guide* lists painters/printers to which GRASS paint/print output can be sent. In addition to hardcopy output devices (printers), a "preview" driver also exists to send paint output to a user's graphics display monitor. User sites can also elect to write new device drivers. The *GRASS Programmer's Manual* and the *GRASS Installation Guide* discuss some of the requirements of device drivers.

p.select - Selects a device (printer) for GRASS hardcopy output. Outputs can also be previewed on the graphics display monitor.

11.3. Printing Hardcopy Map Output

The below commands exist to print the output produced by GRASS *paint* commands.

p.map - Command language interface to color hardcopy and graphics monitor output.

p.screen - Prints a graphics monitor display image file that has been saved by *d.savescreen*.

12. Report Generation

Several commands exist in GRASS to report information about a map's contents, or the results of an analysis on one or more maps, back to the user. The user can also develop macros specific to his needs to prepare other types of reports (see section entitled "Macro Development," and past issues of the newsletter *GRASSClippings*).

12.1. Reports on Contents of Single or Multiple Maps

The following GRASS commands report on the contents of one or more maps.

d.measure -	Measures the lengths and areas of features drawn by the user in the active display frame on the graphics monitor.
d.what.rast -	Allows the user to interactively query the category contents of multiple raster map layers at user-specified locations within the current geographic region.
d.what.vect -	Allows the user to interactively query the category contents of multiple (binary) vector map layers at user-selected locations within the current geographic region.
d.where -	Identifies the geographic coordinates associated with point locations in the active frame on the graphics monitor.
r.describe -	Prints terse list of category values found in a raster map layer.
r.info -	Outputs basic information about a user-specified raster map layer.
r.report -	Reports statistics for raster map layers.
r.stats -	Generates area statistics for raster map layers.
r.volume -	Sums cell values within clumps and calculates volumes and centroids of patches or clumps.
r.what -	Queries raster map layers on their category values and category labels.
v.stats -	Displays information about a user-specified GRASS vector file.